A

DESCRIPTIVE TREATISE

ON

MINING MACHINERY,

TOOLS, AND OTHER APPLIANCES USED IN MINING.

BY

GEORGE G. ANDRÉ, F.G.S.,

ASSOC. INST. C.E.; MINING CIVIL ENGINEER; MEMBER OF THE SOCIETY OF ENGINEERS.

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CHAPTER I.

EXPLORING MACHINERY.

THE work of examining the rocks of a locality for the purpose of discovering the mineral deposits of commercial value contained in them is known to miners as "exploring" or, more commonly, "prospecting"; and the machines used in these operations are hence described as "exploring, or prospecting machines." These consist mainly of boring tools and the apparatus needed to work them. Earth-boring tools constitute a very important class of mining machines, and their importance is increasing as new improvements are introduced into their design and construction. In no class of machines for mining work has greater progress been made within recent times than in this. The discovery of the vast petroleum deposits of America furnished a powerful incentive to mechanicians and engineers to improve the tools previously in use and to adopt more expeditious methods of working them; and the desirability of obtaining more exact information concerning the nature of the strata passed through in mineral explorations led to the introduction of new systems whereby solid cores could be extracted from the bore-hole. The exigencies of American practice, and the great experience gained in the oil regions of the United States, have conduced to modify in an important degree the slow methods of boring which are still employed in Europe. It is to be remarked that the American engineers have worked in the direction of simplicity, while the Germans, to whom we owe many valuable inventions, have rather advanced in the contrary direction. In the present work, attention will be chiefly directed to the more successful practice of the former. A detailed description of the tools and the methods of boring generally adopted in Europe will be found in the author's 'Mining Engineering,' and an exposition of the conditions under which earth boring may be successfully prosecuted is also given in that work. The most important of these tools and apparatus are, however, illustrated on Plates I. to IV.

HAND-BORING.—A set of hand-boring apparatus consists of the "head-gear," by means of which the tools are worked from surface; the "rods" which are used to connect the tools with the head-gear; and the tools by means of which the perforation is made. Of the last, there are two kinds, the *cutting tools*, which are used to penetrate the rock, and the *clearing tools*, which are used to remove the debris that collects in the bore-hole. Besides these, a set of auxiliary tools is required to extract broken tools from the bore-hole in case of a fracture occurring; such instruments are described as *extracting tools*.

Head-Gear.—The head-gear consists of a boring frame, or shear-legs, with the accessory parts

and appliances for raising, lowering, and turning the tools. The use of the boring frame is to furnish an elevated point of support from which the rods attached to the tools may be conveniently suspended. The rods have to be very frequently raised for the purpose of changing the cutting tool and clearing the bore-hole; and it is obvious that the time required for the performance of this operation will, in a great measure, depend upon the height of the frame. If the height of this structure were equal to the depth of the bore-hole, the rods might be withdrawn at one lift. If it were equal to half the depth, one half the length of the rods might be withdrawn at one lift; but this half would then have to be disconnected from that remaining in the bore-hole by unscrewing the joints, and the latter half subsequently raised by a second lift. So if the height of the frame were one-fourth the depth of the hole, the rods would have to be raised in four lifts, and three joints would have to be unscrewed. Thus it will be seen that a high boring frame saves much labour and time, by increasing the length of the "offtake," as it is called; and that for deep borings a high frame is practically indispensable. The height found most convenient in practice is from 45 to 60 feet. Whatever the height may be that is adopted, it is essential that it be a multiple of the lengths of which the rods are made up, so as to bring the joint to be unscrewed a convenient distance above the top of the bore-hole. Thus, if 15-feet lengths are employed, the boring frame must be 30, 45, or 60 feet high; whilst if the lengths are only 10 feet, the height must be either 30, 40, or 50 feet.

The support furnished by the top of the boring frame is provided with a pulley, usually of cast iron, and grooved to receive a rope. This rope is attached at one end to the rods, and at the other to a windlass, by means of which the rope is drawn in and the rods raised. This windlass forms an essential part of every boring frame. It is in most cases fixed upon the frame at a convenient height above the ground, and is worked either with an intermittent motion by levers and ratchet-wheel and pawl, or with a continuous motion by winch handle, as in the case of a common drawing well. The former method is unsuitable for any but small depths, and even in such cases is inferior to the latter. Sometimes the windlass is arranged with a vertical axis, and worked with horizontal bars, like a capstan. When the depth and, consequently, the weight of the rods, become great, the windlass is worked by intermediate gearing, which may be so contrived as to increase the speed when a large portion of the weight has been taken off. In very deep borings, a steam-engine may be used to work the windlass. In all cases, a brake is attached to regulate the descent of the rods.

The sludger is the clearing tool generally employed, and being used independently of the rods, it is usually provided with a special pulley and windlass of smaller dimensions. This windlass is, like the large one, fixed to the boring frame; but for convenience, upon the opposite side, and furnished with a sufficient quantity of rope. The pulley is so contrived that it may run out exactly over the bore-hole when about to be used, and back again out of the way of the rods when done with. The sludger being swung over the hole, is lowered rapidly by its own weight, its descent being checked by a brake upon the windlass. To raise it, the windlass is turned by winch handles, and these are also made use of to produce the reciprocating or "pumping" motion required to fill the sludger. But sometimes this motion is derived from the oscillating lever by winding the rope two or three times round the head.

For deep borings by hand power, the frame shown in Figs. 1, 2, and 3, is a very suitable one. This boring frame consists of two pairs of shear-legs, of 12 inches by 9 inches scantling, set into the projecting ends of the side pieces of a strong rectangular wooden framing, constructed of balks, 12 inches by 9 inches for the side pieces, and 9 inches by 9 inches for the end pieces. The

timbers of each pair of legs have a slight inclination towards each other, being 3 feet 8 inches apart at the bottom, and 14 inches at the top, in a vertical height of 30 feet. These timbers are stayed at intervals of 3 feet by horizontal wooden ties, each 9 inches by 6 inches, mortised into them, and keyed on the outside with wooden keys. The two pairs of legs are connected at the top by two cross-pieces, into which they are mortised: these pieces carry the pulleys. One pair of the shear-legs is provided with stout diagonal timbers fixed between them and the bottom framing, for the purpose of carrying the windlass, which is moved by spur gearing, and furnished with a ratchet-stop. The barrel of this windlass is 18 inches in diameter, and the proportion of the driving to the driven gear is 1 to 3. The two top cross-bars carry a horizontal wrought-iron axle, upon which two independent cast-iron guide-pulleys run loosely. The use of the two pulleys is to save time in raising and lowering the rods. To effect this object, the ends of two ropes are led over the pulleys and coiled in contrary directions upon the barrel of the windlass. By this arrangement, one of the ropes is always down in readiness to be attached to the rods the moment the offtake has been removed, without the labour of uncoiling it from the windlass. The importance of saving time in all boring operations renders the adoption of the double-pulley arrangement desirable in all cases of deep borings.

For the purpose of raising and lowering the sludger, a pair of traverses, 9 inches by 6 inches, is fixed across from one pair of shear-legs to the other, at a distance of about 8 feet below the top traverses supporting the pulleys. These pieces, which are mortised and keyed into the shear-legs, are intended to carry another and smaller pulley, mounted on a cast-iron frame capable of motion between horizontal wooden slides provided for the purpose, and fixed upon the traverses. The slides are made to project beyond the shear-legs, and are furnished with a roller, as shown in the figures, for the purpose of carrying the rope out clear of the frame. The end of the rope, after being led over the pulley and the roller, is brought down and wound upon a smaller windlass fixed upon the shear-legs opposite those carrying the larger windlass. The sludging windlass is provided with a brake, to regulate the descent of the tool, as before described; and it may be remarked here that such brakes should be self-acting, the power being obtained preferably by means of a weight. The rope used for the sludger will be $\frac{3}{4}$ inch or 1 inch in diameter, according to the dimensions of the tool. Hempen rope is usually employed, but aloe fibre, allowing of smaller dimensions, has often been used with advantage.

Next to the boring frame, the most important part of the head-gear is the oscillating or "rocking" lever. It is by means of this lever that the requisite motion is communicated to the rods when working the cutting tools. It consists of a piece of straight-grained ash, provided with an iron axle, upon which it turns as a fulcrum. This axle is supported upon a wooden framing, composed of four upright pieces, fixed at the bottom in two cross timbers, inserted for that purpose into the framing of the shear-legs, and connected in pairs at the top by two cross-pieces, into which they are mortised. The two inner upright pieces are connected in the same way, to afford a support for the lever axle. The height of the support thus obtained is about 5 feet 6 inches. The dimensions of the lever will be determined by the weight of the rods, and will therefore vary with the depth of the bore-hole. The same conditions will determine the proportions of the iron axle and its attachments. This axle is fixed upon the lower side of the lever by means of straps and bolts, in the manner shown in Figs. 4 to 7, an iron carriage being bolted down to the framing to carry the axle. As these parts will be subjected to severe strains, the materials should be of good quality,

and the dimensions ample. The proportion of the shorter to the longer arm of the lever will be determined by the weight of the rods and the length of the stroke. One to 4 and 1 to 5 are the usual proportions; but in some instances as much as 1 to 9 has been adopted. The total length of the lever will depend somewhat upon the proportion of the arms, but in most cases from 10 to 12 feet will be found to be a convenient length. And with a proportion of 1 to 4, or 1 to 5, and a bore-hole of considerable depth, say from 500 to 700 feet, a scantling of 9 inches by 7 inches will be sufficient. The diameter of the axle in such a case should be $2\frac{1}{4}$ inches. The length of the stroke should, as far as is practicable, be proportioned to the hardness of the rock which is being bored through. For moderately soft clay, 6 inches may be sufficient; but compact limestone may require 24 inches, or even more.

To allow several men to work at the end of the longer arm of the lever, a cross-bar of suitable dimensions is affixed to it. This cross-bar should be of tough ash, of circular section, and of such a diameter as to be conveniently grasped by the hand; it should be fixed, by means of iron straps, upon the upper or upon the lower side of the lever, and never passed through it or notched into it. Instead of the cross-bar, straps of iron provided with a hook at each end may be fixed across the upper side of the lever, leaving the hook projecting over the edge. Short pieces of rope, with a ring on one end, and a piece of wood, of circular section and about 8 inches in length, on the other end, may be used instead of the cross-bar, by placing the ring over the hook and grasping the piece of wood to pull by. In this way, four men can work with two hooks on each side, or six men with three hooks. One advantage gained by this method of working the lever is the directness of the strain. With the cross-bar, a preponderance of force on one side—and such a preponderance must always exist, since the men will never be exactly equal in strength—produces a torsional strain great in proportion to the amount of the preponderating force and the leverage of the cross-bar. To steady the lever, the longer arm is sometimes made to move between guides.

The head of the lever should be formed of a sector of a circle, the centre of which is the point of support. This is needed to raise and lower the rods in a straight line. Usually the sector-head is of cast iron, as shown in Fig. 4. Above the head a stout hook is firmly fixed by means of bolts. In this hook the rods are hung, a short piece of chain, or preferably of flat hempen rope, furnished with a ring at one end, and a swivel-head and hook at the other, being required when the lengthening stirrup is used. As the head of the lever partly overhangs the bore-hole, the axle must be so set in its bearings that the lever may be withdrawn when it becomes necessary to use the sludger. The usual manner of providing for this requirement is shown in Fig. 6, where the construction of the carriage allows the lever to be readily lifted off its bearings.

For the purpose of suspending the rods from the oscillating lever or the pulley, the top length of the rods terminates above the surface of the ground in a stirrup, the construction of which allows the rods to be turned round during the operation of boring, and to be lowered as the boring progresses. Several forms of stirrup are in use, but the most convenient is that represented in Fig. 21. This stirrup keeps the upper end of the rod always at the same height above the ground, a necessary condition for the perfect working of the lever, and it enables the borer to see exactly the progress that is being made at the bottom of the hole. The construction of the stirrup will be clearly seen in the figure.

An essential part of the surface apparatus is the bore-hole guide-tube, shown in elevation and in plan in Figs. 8, 9, and 10, Plate II. This tube is of wood, and for bore-holes of

ordinary dimensions is about 12 inches in diameter and 6 feet in length. The diameter of the bore of this tube is the same as that of the bore-hole, so that the thickness of the wood is about $4\frac{1}{2}$ inches for a 3-inch hole. The guide-tube should be inserted into the bore-hole to a depth that will leave about 10 inches of its length above the surface of the ground, and firmly held in its position by four pieces of timber, 9 inches by 6 inches in section. These pieces are laid upon the ground in pairs, one piece on each side of the tube, the pairs being at right angles to each other. The ends of the pieces forming each pair are then pressed partially together, to make them tightly clasp the tube, and are held in a state of tension by iron straps across the ends, and these ends are firmly fixed to the ground. Sometimes they are fixed to the framing in which the shear-legs are set; but this practice is not to be recommended, as the vibration of the framing tends to produce injurious effects. When a staple is sunk, they are, of course, set at the bottom of the staple. Various means of fixing these timbers may be employed, the only necessary condition being that there shall be no liability of their becoming loose during the progress of the work. The upper surfaces of these timbers are an inch below the top of the tube. The aperture of the tube is provided with a pair of iron shutters, opening and closing horizontally, as shown in Fig. 8. The form of these shutters and the mode of fixing them will be clearly seen from the figure. Each shutter is notched to form a square aperture of $1\frac{1}{8}$ inch wide, through which the rods may freely move from joint to joint when the shutters are closed. The use of these shutters is to prevent anything from falling down the bore-hole. Instead of this kind, flap shutters may be used. They consist of two semi-circular iron disks hinged upon the tube, and opening vertically like a clack-valve, a notch in each forming the aperture for the rods, as in the preceding kind.

The top length of the rods terminates in a swivel-head, by which it is suspended from the rocking lever. For the purpose of adjusting the height of the head to the requirements of the lever, several short lengths are needed, varying from 1 foot to 3 feet, which are screwed on as the boring progresses, the shorter lengths being removed and a larger one substituted at each change.

These lengthening pieces, one of which is represented in Fig. 26, are all provided with a screwed socket. Sometimes they are furnished with an eye through the shank just below the head, through which a piece of wood is passed to form a lever, by means of which the rods are turned round during the operation of boring. This arrangement is common in Belgium; but in England it is more usual to employ the brace-head or tiller for this purpose.

The tiller may be of wood or of iron. When of wood, it consists of a piece of ash, 4 inches in diameter, square in section in the middle, and rounded off and reduced in size towards the end, as shown in Fig. 27. The middle portion is provided with a notch one inch square to receive the rod, one side of the notch being formed by an iron plate turning on a bolt at one end and fixed at the other by a screw. On withdrawing this screw, the plate drops and leaves the notch open. Another screw through the centre of the plate is provided for the purpose of fixing the tiller upon the rods. When the tiller is of iron, it is constructed in the manner shown in Figs. 28 and 29. It consists of two portions, each 18 inches or 2 feet in length, joined by two screws. To apply the tiller to the rod, the two portions are separated by withdrawing the screws, and the portions are applied one on each side of the rod, and fixed in that position by reinserting and tightening the screws. Or, when the rods are not suspended from the lever, this tiller may be applied by passing it over the head of the upper length. The ends of the tiller are turned up, as shown in the figure, to afford a convenient hold for the workmen.

For the purpose of raising and lowering the rods, "lifting dogs" are required. This consists of a claw-hook, through the shank of which a ring is passed, by means of which it is attached to the rope. When in use, the claw is placed under the head on the shoulder of the top length of rod, and the latter hauled up or lowered by means of the windlass. The lifting dog is represented in Figs. 32 and 33.

Another instrument required for raising or lowering is the "nipping fork" or "tiger." When the rods have been hauled up as far as the height of the shear-legs will allow, they must be supported in that position while being unscrewed. For this purpose, the nipping fork, represented in Fig. 31, is placed upon the top of the guide-tube beneath the joint in the rod, and the latter lowered till the joint rests upon the fork. In like manner, in lowering, the rods are let down till the lifting dog rests upon the fork; the next offtake is then screwed on, and the lifting dog hanging from the other pulley placed under the shoulder of the top length, and the rods slightly lifted thereby to allow the lower dog to be removed. When only one lifting dog is used, after the first offtake has been removed, a short swivel-head lengthening piece must be screwed on to each subsequent offtake, to afford a hold for the dog. Provided the shutter of the guide-tube be made sufficiently strong, they may be made to fulfil the purpose of the nipping fork.

For the purpose of screwing up and disconnecting the rods, a kind of wrench, called a "hand-dog," is required. This instrument is shown in Fig. 30, from which its construction will be understood without description.

Rods.—The rods by means of which the excavating tools are worked from the surface constitute a very important part of the boring apparatus. They consist usually of bars of iron 1 inch square, for boring of ordinary dimensions. Other sections have been employed, notably the circular and the octagonal; but the greater simplicity of the square section, and the advantage which it possesses of allowing the application of keys and spanners to any portion of its length, have caused it to be preferred to the more complex forms. The ordinary forms are shown in Figs. 22 and 23.

The rods are generally made up of 10 or 15 feet lengths, and the several lengths of rod are connected by a screw-joint. Other modes of connection have been employed, but all have failed in practice, some for one reason and some for another, leaving the screw-joint in universal use. All the joints should be identical in every respect, so that any two lengths may be connected together; and in making up the rod, care should be taken always to have the socket on the lower end of each length, to prevent rubbish from being jammed into it. The enlarged portion at the joint serves as a point of support to suspend the rods from during the operations of raising and lowering. A grave objection to the employment of iron rods for deep borings is their great weight. Two methods have been proposed of overcoming this difficulty: the first is the substitution of wooden rods for iron ones when the depth is great. Such rods, with their iron connections, lose the greater part of their weight in water, and thus are not exposed to the danger mentioned. They have been successfully employed in many instances. These rods are made of sound, straight-grained pine, in lengths of 25 and 35 feet, have a square section of not less thau $2\frac{1}{2}$ inches side, with the angles slightly planed off. They are connected by iron screw-joints in the same manner as the iron rods, each end being provided with an iron joint-piece forming a socket into which the rod is bolted, as shown in Fig. 23. A fatal objection to wooden rods for small borings is the necessity for a large section. Less than 2 inches side could not be used, and for great depths 3 inches and 4 inches would be required. But when the bore-hole

is of sufficient diameter, they may be employed with advantage in some cases; and, as a matter of fact, they are frequently adopted for deep borings on the continent of Europe.

The second method proposed possesses greater advantages, inasmuch as it removes the difficulty without abolishing the iron rods. It consists in forming the rods of two distinct portions: a short and massive part at the bottom, to which the cutting tool is attached, and on which alone the force of the shock is expended; and the rod proper, which is used solely to raise the former part, and which, not being attached to it in an invariable manner, is not exposed to the shocks occasioned by the percussive action of the former. As this method allows all the advantages attending the use of iron rods to be retained, it is by much the more important of the two, and has, consequently, been very generally adopted. The forms of construction by which the latter method has been carried out have undergone numerous modifications since its first introduction. But, as in the case of the tools, the lessons of experience have led to the abandonment of all or most of the recent devices in favour of the extremely simple form which was first proposed, and which is due to the inventive genius of Œynhausen. This joint is known as the "sliding joint," and is the only one that can be relied upon for borings of an ordinary character; for it must be evident that complicated devices are totally unsuitable for use at the bottom of a deep bore-hole, where they are far removed from reach and sight. The construction of the sliding joint will be clearly seen in Figs. 24 and 25. The lower part to which the cutting tool is affixed terminates upwards in a head, moving in a slot in the lower extremity of the upper portion constituting the rods proper. When the rods are raised, the tool is lifted by this head, which then rests upon the bottom of the slot. On dropping the rods to produce the percussive action of the tool, the latter falls with the former till it comes in contact with the rock at the bottom of the hole, when it is abruptly arrested and thereby subjected to a violent shock. But the rods continue the descent by allowing the head of the arrested portion to slide up in the slot, and by that means the shock is confined to the part carrying the tool. As soon as the head of this part begins to move up the slot, the end of the lever at surface to which the rods are attached comes in contact with an elastic stop, which is capable of bringing the rods to rest within the space allowed by the play of the slot. In this way the descent of the rods is gradually arrested, and injurious shocks avoided, without diminishing in any degree the action of the cutting tool. Another advantage, of no small importance, that has been gained by the use of the sliding joint, is the possibility of considerably reducing the section of the rods, which are required only to raise the part to which the tool is affixed.

Tools.—The simplest and commonest form of cutting tool is that shown in Figs. 11 and 12, which is known as the "flat chisel" or "straight bit." It is made of the toughest iron and steeled at its cutting edge with the best material. The length is usually 18 inches; at the upper end it is provided with a thread by means of which it is screwed to the rods. This form of tool is applicable to all but the softest and the hardest strata. The ease with which it may be re-sharpened is a quality that commends it to the choice of the practical man. For penetrating very hard rock, the form shown in Figs. 13 and 14, and variously known as the "diamond-point," "drill," or "V chisel," is used. This tool differs from the straight bit only in the form of its cutting edge, which is more suitable for rock of a highly resistant character. For boring through gravel, the form of cutting tool shown in Fig. 15 is used. It consists of two cutting edges at right angles to each other, one of them being curved towards its extremities. This form is known as the T chisel. The "auger" borer, shown in Fig. 16, is employed in boring through plastic clay and loose sand. This tool is

similar to that used for boring in wood. The bottom is partially closed by the lips, which are turned down to a greater angle than in the case of wood augers. The clay auger is made of greater lengths than the chisel bits, but it terminates upward in the same form. Usually it is half cylindrical, as in the figure; but sometimes it is made wholly cylindrical, with the exception of a length of about 6 inches at the bottom, where it is left open to allow of the admission of the material which is being bored through. When used in clay, this tool, on being raised to surface, carries the " core " with it.

For clearing the bore-hole of the debris of the rock chipped off by the cutting tool, an instrument called a "sludger," Fig. 19, is used. This instrument is so called, because it removes the debris in the form of *sludge* or mud. It consists of a wrought-iron cylinder, a little less in diameter than the cutting tools, the lower extremity of which is furnished internally with a ball-valve. This valve is of metal, and its weight is proportioned to the degree of fluidity of the matters to be extracted. It is made to rest upon a conical seating formed by an annular piece riveted to the cylinder. The sludger is worked by jerking it up and down in the bore-hole on the end of a rope. During the descent of the tool, the valve is raised by the water in the hole, and as it sinks by its own weight into the debris, the latter passes above the valve. During the ascent of the sludger, the material which has entered acts, with the water, to close the valve. By this means, the escape of the sludge is prevented, though a large portion of the water passes out through the accidental interstices caused by small pieces of stone upon the valve seating. The action of the sludger is very effective, as much as a cubic yard of sludge being sometimes removed at one time by a large tool. When the operation of " pumping " the sludger has been continued sufficiently long to clear the hole, it is raised and its contents removed by turning it upside down. This instrument will be found illustrated again among the American tools, where it is described as the " Sand-pump."

The materials brought up by the sludger show the nature of the stratum that is being passed through. But as these materials are in a divided state, being reduced to small fragments by the action of the chisel, they indicate but little of the physical condition of the rock-bed, and nothing whatever of its dip. Moreover, their indications concerning the nature of the bed are hardly trustworthy, inasmuch as particles of the higher beds are continually falling from the sides of the bore-hole. As it is highly desirable that full information on all points should be obtained when boring in search of minerals, and especially on the dip of the beds, their physical character, and their geographical age as evinced by contained fossils, it becomes necessary to have recourse to special tools for that purpose. The use of such tools is to bring up a solid core of the rock, and to bring it up in such a condition that the lines of stratification will show the dip of the bed. To obtain this result, the core must be marked relatively to the north point before it is broken from the rock. This is effected by means of a chisel with an eccentric cutting edge. Having previously cleared out the hole, this chisel is lowered, care being taken, by suitable marks on the rods and a fixed plumb-line, that it be not turned in the least degree during the operation. When it has reached the bottom of the hole, two or three light blows are struck without turning the rods, and it is again raised. A special tool, Fig. 17, composed of a number of chisels set in a ring, is then lowered, and worked with light blows in the same manner as the common chisel. By this means an annular space is cut round the marked core. When this space has been cut nearly to the depth of the chisel, the tool is raised, and another special extracting instrument, Fig. 18, let down. This instrument drops over the core, and by means of a wedge thrust in by the weight of the rods, exerts

a sufficient lateral pressure to break it off. The core is held between the wedge and a spring fixed on the inside of the instrument for that purpose, and in this way it is raised to the surface. The inclination of the lines of stratification may then be observed relatively to the mark upon the upper end, and the direction and amount of the dip determined. By repeating this series of operations, a complete section of the strata may be obtained.

It not unfrequently happens that the rods become fractured, and the tools are consequently left at the bottom of the bore-hole. In such a case special tools, called extracting tools, are made use of to remove the fragments from the hole. When the rods have parted either in, or immediately above a joint, the portion in the bore-hole may be seized by an instrument called a "crow's-foot," represented in Fig. 110. This instrument is lowered on the end of the rods into the bore-hole, and turned round till it has grasped the broken rod beneath the joint, when the whole may be raised without difficulty. When the fracture has occurred immediately below a joint, or near the middle of a length, the crow's-foot cannot be used, because the long portion above the joint would catch in the side of the bore-hole on being lifted by the tool. In such a case an instrument called a "bell" is used to recover the last portion. This instrument will be found illustrated among the American tools, where it is described as the "horn-socket." Another extracting tool is the "wad-hook" shown in Fig. 20. This hook is attached to the end of the rods, and lowered as far as the broken portion; when it is turned round till it has taken a firm hold of the rod. It may be used to extract a broken bit, pebble, or any substance that may have accidentally fallen into the bore-hole.

Tubes.—In earth boring it is very frequently necessary to line a portion, or the whole, of the bore-hole with iron tubes. These tubes are provided with screwed plug and socket for joining in the same way as the rods. Other forms of joint are used, but the screw joint, though somewhat more expensive, is to be preferred; the tubes are generally in 10-feet lengths. To line the bore-hole, a length of pipe, the outside diameter of which is equal to that of the hole, is inserted, and driven down till its socket is nearly level with the top of the guide-tube; another length is then screwed on by means of the pipe-clamp represented in Fig. 34, and driven down in like manner. The lower end of the first tube is steeled, and the edge sharpened, to enable it to penetrate readily. The operation of forcing the tubes down the bore-hole is one demanding great care. Proper provision must be made for keeping the tubes perfectly vertical during the driving, to avoid the danger of fracture arising from transverse strains and indirect shocks. The driving is effected either by blows or by pressure. When the former method is adopted, a block of wood, bound with an iron hoop to prevent crushing, and having a hole through the centre sufficiently large to allow the free passage of the rods, is placed upon the socket of the upper length of tubing to receive the blow, the object being to prevent the fracture of the tube by interposing an elastic medium between it and the instrument with which the blow is given. The latter consists of another block of wood bored and bound in the same manner as the first, and constituting a kind of "monkey," to be used as in pile-driving. This monkey is fixed by pressure-screws upon an upper length of rod, as shown in Fig. 35. Several lengths of rod are then screwed on to give weight, and passed through the hole in the lower block, and allowed to hang down the tube and the bore-hole; a rope is then attached to the head of the rod, carried over the pulley at the top of the shear-legs,—the ordinary rope having been lifted off for the occasion,—and wound with one turn upon the windlass. Frequently it will be found convenient to use the sludger pulleys and windlass for this purpose. To work the monkey, two men turn the windlass, a third man holding the end sufficiently taut to enable the former, by means of the friction,

to raise the rods with the monkey attached. The drop is occasioned by releasing the end of the rope. The descent of the tubes may be assisted by giving them a partial turn after each blow by means of the clamp-lever represented in Fig. 34.

MACHINE BORING.—It has already been pointed out that the art of earth boring has, within the past decade, undergone great development in the United States of America in consequence of the discovery of petroleum in large quantities. The improvements consist mainly in the substitution of steam power for manual labour, and the introduction of greater simplicity into the forms and construction of the appliances used. One important feature of the American system of boring is the use of a rope instead of rods in the bore-hole. By the adoption of this flexible suspending medium, which, it may be remarked, was in use centuries ago among the Chinese, a very large proportion of the time expended in raising and lowering the tools is saved. The particular merits of the system will be best understood from a description of the tools and other appliances in use, and of the methods of working them.

The head-gear consists of a boring frame, called the "derrick," Figs. 36 to 38, usually from 60 to 70 feet high; the "working beam," or rocking lever, Figs. 49 to 53, by means of which the jigging motion is given to the tools; the "sampson post," Figs. 39 to 42, upon which the working beam is hung; the "pitman bar," or connecting rod, Figs. 52 to 54, by which the outer end of the working beam is connected to the crank of the band-wheel; the "band-wheel," Figs. 55 and 56, upon the shaft of which is the crank to which the pitman bar is attached; the "jack-frame," upon which the band-wheel is supported; the "sand-pump reel," Figs. 65 and 66, fixed upon the jack-frame and worked by friction from the band-wheel; and the "bull-wheel," or windlass, Figs. 63 and 64, upon which is wound the rope from which the tools are suspended. The connections consist of: a "temper-screw," or stirrup, by means of which the rope is suspended from the inner end of the working beam; a rope, to which the tools are attached; a "rope-socket," Fig. 86, by means of which the attachment is made; a "substitute," Fig. 90, a short bar of round iron having a box at one end and a pin at the other, used in the place of, or with, the sinker bar; the "sinker bar," Fig. 89, a bar of round iron from 10 to 12 feet long, terminating, like the substitute, in a box at one end and in a pin at the other, the use of which, when screwed on to the jars, is to give additional weight to the tools; the "jars," or sliding joint, which are screwed on to the sinker bar, and used to lift the cutting tools and to let them drop; and the "auger-stem," Fig. 88, by means of which the tools are attached to the jars. The auger-stem is in form like the sinker bar, but it is longer, the usual length being from 20 to 24 feet. The cutting tools consist of: two straight "bits," for cutting away the rock; and a flat and a round, or a half-round reamer, to follow the bit in order to enlarge the hole, and to keep it true and round. The clearing tool used is the "sand-pump," or sludger. Besides these, two wrenches, Fig. 94, are required for screwing up and unscrewing the connections. The engine used is generally of the portable class, and of about 25 horse-power.

The foregoing tools and apparatus are described by Andrew Cowen and Walters R. Johns as follows. The derrick is a tall framework, in the shape of a pyramid. It was formerly built of rough poles, or hewn timber, the bottom being from 10 to 12 feet square, the poles, four in number, being erected one at each corner, 30 feet in height, converging towards each other, forming a square at the top of $2\frac{1}{2}$ feet, with girths and braces at suitable distances to make the structure sufficiently strong for the work required of it. Derricks are now built of sawn lumber or planks, 2 inches thick, and from 6 to 8 feet wide, the two edges being spiked together, forming a half square on each

corner of the foundation, which is from 14 to 16 feet square, and in some localities more. The derrick is put up in sections, being braced transversely as it goes up, in order to secure the strength necessary, until it reaches the proper height, which for deep holes is about 56 feet; for shallow ones, less height and a lighter derrick is required; at the top it forms a square of from 2 to 3 feet.

On the top of the derrick is put a strong framework for the reception of a pulley, Figs. 69 and 70, over which the drill-rope passes. The floor of the derrick is made strong by cross sleepers, covered with planks or boards. A roof for the protection of the workmen is laid with boards across the girths, some 10 to 12 feet above the floor. In cold weather the sides are boarded up. The bull-wheel, Figs. 63 and 64, as it is called, is a shaft of timber, 6 to 8 feet long, fastened like the shaft of a common windlass, and 6 to 8 inches in diameter, the ends of the shaft being banded with iron, and a journal of inch-iron driven into each end for it to revolve upon. Mortises are made through this shaft 8 or 10 inches from each end, for the arms of the wheel. The wheels are usually made from 6 to 8 inches thick on the face, with strips of plank sunk into and spiked on to the outer surface, for the double purpose of receiving the rope-belt and connecting it with the band-wheel for drawing up tools, tubing, &c., out of the well, and for the workmen to take hold of with their hands when working it without the help of the engine. The bull-wheel is placed on the side of the derrick next to or opposite the band-wheel and engine, as the workmen may desire. The drill-rope is coiled on this shaft between the wheels, one end being passed from it over the pulley on the top of the derrick, and attached to the tools.

The sampson post is of hewed timber, 12 to 15 inches square and usually 12 feet in height, erected on heavy framed timbers which cross each other, and are bedded firmly in the ground, and having a mortise to receive the tenon on bottom of post; there is also a brace on each side, reaching nearly to the top of the post. On the top of this are the irons, Figs. 43 to 45, fitted to receive the working beam, which is balanced on the top of the sampson post, admitting of the rocking motion required in drilling and pumping. The working beam is a piece of timber, from 20 to 26 feet long, 8 or 10 inches square at each end, 8 by 14 to 16 inches in the middle, with iron attachment in the centre, fitting to a similar one on the sampson post. To the end over the bore-hole is an iron joint, Figs. 50 and 51, for attaching the temper-screw when drilling, and sucker-rods when pumping. On the other end of the working beam is an iron joint, Figs. 46 to 48 and 52 and 53, for attaching the pitman-bar, which connects the same with the crank, or band-wheel shaft. The band-wheel, shaft, and crank, Figs. 57 and 58, spider for wheel, Figs. 59 to 62, pitman, and working beam, as well as all the other parts of the machinery, are shown in the plates already referred to.

The band-wheel is usually about 6 feet in diameter, with a 6-inch face, built in various styles, according to the fancy of the builder, and is placed upon a strong frame built for its reception, called the jack-frame. The jack-frame is secured in position by two heavy timbers, bedded into the ground with jams sunk into them to receive the sills of the jack-frame, to which they are keyed fast. The engine is usually placed from 8 to 12 feet distant from the band-wheel, and connected by rubber or other belting. The belting in general use is 6 inches in width.

On Plate XI. the general arrangement of the several portions of the surface apparatus is shown. The engines used, as already remarked, are mostly of the portable class; the engine-house consists merely of a light wooden shed to protect the attendants from the weather. It is made sufficiently spacious to contain a forge for re-sharpening the cutting tools, and a small store of materials; in some cases, sleeping bunks for the workmen are added.

When all the parts of the apparatus have been placed in position, the iron guide-pipe, or driving pipe, as it is called, Fig. 83, is first driven down to the solid rock. This pipe acts as a conductor, and prevents earth or stones from falling into the pit or hole while the drilling is going on. The driving pipe in general use is of cast iron, 6 to 8 inches in diameter, having walls of about one inch in thickness, and is in lengths 9 to 10 feet long. The driving of this pipe is a work of difficulty, requiring the utmost skill, since the pipe must be forced down through all obstructions often to a great depth, while it must be kept perfectly vertical. The slightest deflection from the vertical ruins the well, as the pipe acts as the conductor for the drilling tools. The process of driving is simple, but effective: Two slide-ways, Figs. 81 and 82, made of plank, are erected in the centre of the derrick to the height of 20 or more feet, 12 to 14 inches apart, with edges in toward each other, and the whole made secure and plumb. Two wooden clamps or followers are made to fit round the pipe, and slide up and down on the edges of the ways. The pipe is erected on end between the ways, and held vertical by these clamps, and a driving cap of iron is fitted to the top. A battering ram is then suspended between the ways and arranged to drop perpendicularly upon the end of the pipe. The battering ram is of timber, 6 to 8 feet long, and 12 to 14 inches square, banded with iron at the lower or battering end, with a hook in the upper end to receive a rope. When the whole is in position, a rope is attached to the hook in the upper end, passed over the pulley of the derrick, and led down to and passed round the shaft of the bull-wheel. When everything is in readiness to drive the pipe, and the belt connecting the engine and band-wheel, and the rope connecting the band-wheel and bull-wheel, called the bull-wheel rope, are adjusted, the machinery is put in motion by the engineer, a man standing behind the bull-wheel shaft, grasps the rope attached to the ram and coiled round the bull-wheel shaft, holds it fast, and takes it up in his hands, thus raising the ram to its required elevation; he then lets it fall upon the pipe, and thus by repeated blows the pipe is driven to the requisite depth. When one joint of pipe is driven, another is placed upon it, and the two ends secured by a strong iron band, and the process continued as before. The pipe has to be cleaned out frequently, both by drilling and sand-pumping. Where obstacles, such as boulders, are met with, the centre-bit is put in requisition, and a hole two-thirds the diameter of the pipe is drilled through the same. The pipe is then driven down, the edges of the obstacle being broken by the force applied, the fragments falling into the space cleared by the bit. When this cannot be done, the machinery and the derrick is moved sufficiently to admit of the driving a new set of pipes. It sometimes happens that the pipe is broken, or diverted from its vertical course by some obstacle. The whole string of pipes driven has, in such a case, to be drawn up again and the work commenced anew; if this is not possible, a new location is sought.

After the pipe is driven the work of drilling is commenced. The drilling rope, which is generally $1\frac{1}{4}$-inch hawser-laid cable, of the required length, from 500 to 1000 feet, is coiled round the shaft of the bull-wheel, the outer end passing over the pulley on the top of the derrick down to the tools, and attached to them by a rope-socket. When connected these are from 30 to 40 feet in length, and sometimes more, weighing from 800 to 1600 lbs., according to the depth required to be reached. The process of drilling, until the whole length of the tools are on, and suspended by the cable, is slow. When the depth required to suspend the tools is reached, the attachment between the working beam and the drilling cable is made by means of a temper-screw, Fig. 84, suspended from the end of the working beam, and attached to the rope by a clamp. The temper-screw, which is provided with a coarse thread, is from 2 to 3 feet in length; it works in a thin iron frame, and is furnished with a wheel at the lower end of the screw for the driller to let out the same as is

required. As the drill sinks down into the rock, the screw is let down by a slight turn of the wheel by the driller, some allowing a full revolution every few blows of the bit, others once only in a few minutes, according to the hardness of the rock which is being drilled through.

The "jars," as they are called by oil miners, Fig. 87, play a highly important part in the work of drilling. They are two long links or loops of iron or steel, sliding in each other. Drillers always allow about from 4 to 6 inches play to the jars, which they call the "jar," and by this they can tell when to let down the temper-screw. With the downward motion, the upper jar slides several inches into the lower one; by the upward motion, it is brought up, bringing the end of the jars together with a blow like that of a heavy hammer on an anvil, making a perceptible jar. Experienced drillers can, as soon as they take hold of the rope, tell how much "jar" they have on.

In drilling, the tools are alternately lifted and dropped by the action of the working beam in its rocking motion. One man is required constantly in the derrick to turn the tools as they rise and fall, to prevent them from becoming wedged fast, and to let out the temper-screw as required. This is one of the most important duties of the work, requiring constant attention to keep the hole round and smooth. The centre-bit is run down the full length of the temper-screw. The centre-bit, Figs. 95 to 97, is about $3\frac{1}{2}$ feet in length, with a shaft $2\frac{1}{2}$ inches in diameter, and a cutting edge of steel $3\frac{1}{2}$ to 4 inches in width, with a thread on the upper end by which it is screwed on to the end of the auger-stem. The reamer, Figs. 98 to 103, is about $2\frac{1}{2}$ feet in length, having a blunt instead of a cutting edge, with a shank $2\frac{1}{2}$ inches in diameter, terminating in a blunt extremity $3\frac{1}{2}$ to $4\frac{1}{2}$ inches in width by 2 inches in thickness, faced with steel. The weight of heavy centre-bits and reamers averages from 50 to 75 lbs. each.

The centre-bit is followed by the reamer, to enlarge the hole and make it smooth and round.

The sediment, or battered rock, is taken out after each centre-bit, and again after every reamer, by means of a sand-pump, Figs. 104 to 106, let down in the well for the purpose. The sand-pump now in use is a cylinder of wrought iron, 6 to 8 feet in depth, with a valve at the bottom and a bail at the top, to which a half-inch rope is attached, passing over a pulley suspended in the derrick some 20 feet above the floor, and back to the sand-pump reel, attached to the jack-frame, and coiled upon the reel-shaft. This shaft is propelled by means of a friction pulley, controlled by the driller in the derrick by the rope attached. The sand-pump is usually about 3 inches in diameter. Some drillers use two, one after the centre-bit and a larger one after the reamer, the two being preferable. When the sand-pump is lowered to a requisite depth, it is filled by a churning process of the rope in the hands of the driller, and is then drawn up and emptied. This operation is repeated each time the tools are drawn up out of the well, the pump being let down and drawn up a sufficient number of times to remove all the drillings. The fall of the tools is from 2 to 3 feet. This labour goes on, first tools and then sand-pump, until the well is drilled to the required depth.

Several kinds of regulating tools are used, though they do not constitute a portion of every set. For the purpose of keeping the hole straight, the "winged" substitute, shown in Fig. 109, is often used. To straighten a crooked hole, recourse is sometimes had to the "hollow reamer," represented in Fig. 107; sometimes the "star reamer" is employed for the same purpose. This tool is shown in Fig. 108. If skill and care, however, are exercised in the execution of the boring from the beginning, these tools are seldom needed.

The rate of boring with the machinery described varies from 2 inches an hour in very hard rock to 10 inches, or even 12 inches, in shale. This rate is greatly in excess of that attainable by the system of rods.

Two recent improvements are to be observed in the sand-pump: first, the valve, with a drop stem to open it on reaching the bottom of the boring, and second, the piston, which keeps its place at the bottom of the pump while being lowered, but which while being drawn up fills the pump, by suction, with the loose debris and water.

The first few hundred feet are generally gone through without difficulty, provided all the arrangements have been made with care at the beginning, and the drillers are skilful. Difficulties occur farther down, that test to its utmost endurance the most persistent energy. Sometimes they are attributable to a want of caution on the part of the driller, from imperfection in the material of, or improper dressing, or tempering the drill, but more often from circumstances unforeseen and unavoidable. In its passage the drill not unfrequently dislodges gravel or fragments of hard rock, that have a tendency, and often do wedge it fast in the hole, from which it is only dislodged by the most persistent "jarring."

The reamer is also subject to the same mishap, or a sand-pump breaks loose from its rope, and has to be fished up. When the bit or reamer becomes so firmly imbedded as to render its removal impossible by jarring or breaking it in pieces, the well is abandoned. Sometimes a bit or reamer breaks, leaving a piece of hard steel fastened securely in the rock several hundred feet below the surface. Where the fragment is small it is pounded into the sides of the well, and causes no further annoyance. When it is larger the difficulty is greater, and not unfrequently insurmountable. The bit or reamer sometimes becomes detached from the auger-stem by the loosening of the screw from its socket; this difficulty is often greatly heightened from the fact that the workman may not be aware of its displacement, and for an hour or two be pounding on the top of it with the heavy auger-stem. Various plans are resorted to in order to extract the fastened tool, and a large number of implements have been devised for "fishing up" the same. Many persons have become so expert and successful as to adopt this as a regular calling. The first instrument used is an iron with a thin cutting edge, straight, circular, or semicircular, acting as a spear, or to cut loose the accumulation around the top, and along the sides of the refractory bit or reamer, so as to admit a spring socket, that is lowered by means of the auger-stem over the top of it, and lays hold of the protuberance just below the thread. If the socket can be made fast, the power of the bull-wheel and engine is brought into requisition, and in a great number of cases it is brought to the surface.

In the jarring and other operations rendered necessary in cases of this kind, the entire set of tools, 40 to 60 feet in length, may become fastened; and cases are of frequent occurrence where two and even three sets of tools have become fastened in a bore-hole as they were successively let down to extricate the first ones. A most effective instrument now commonly used for the extraction of broken tools consists of a number of heavy iron rods, similar to an auger-stem, weighing about 10 tons; to the end of the rods is attached a socket, or bell, which is lowered over the head of the tools and secured fast to them, the joints of the rods being provided with left-handed screws. When a set of tools have become fast each separate piece may by this means be unscrewed and raised to surface. The rods are lowered and raised from the top by jack-screws.

A running stratum often occasions much difficulty. Sometimes in passing through a bed of soft clay the material will flow into the hole suddenly, and bury 10 or even 20 feet of the tools. In such a case a cutting instrument is attached to rods, and the rope severed by it above the sinker bar. The cutting tool is then replaced by a spear-pointed instrument, with which, by means of a light set of tools, the substance imbedded round the tools is forced out. When they are sufficiently loosened, efforts are made to jar them out, an extra pair of jars being used for this purpose. Instead of the

spear, the "spud" or "spoon," Fig. 112, is frequently used. This instrument is simply half a hollow reamer. The "horn-socket," Fig. 111, is a tapering iron tube, designed to be dropped over and wedged upon the head of a lost tool. The "slip-socket," Figs. 116 and 117, is also intended for the same purpose; but this instrument is provided with dogs or teeth to fall out and catch the tool under the collar. Another and somewhat similar kind of "fishing" or extracting tool is the "grabs" shown in Fig. 118. The "rope-grabs" represented in Fig. 121 are used for grappling the rope or cable; for severing the rope in the bore-hole the "rope-knife," Fig. 120, is used. The "hook," shown in Figs. 114 and 115, is used for grappling lost tools that are leaning against the side of the hole. The "slip-spear," Fig. 119, is used to extract tubing.

Tools for Extracting Tubes.—When the bore-hole has been completed, and the end for which it was undertaken attained, it becomes desirable to recover the tubes used to line the hole. Also when more sets of tubes are required than anticipated, and the diameter of the bore-hole has consequently been so reduced that farther progress is impracticable, it becomes necessary to withdraw the lining and to enlarge the hole from surface. The operation of withdrawing the tubes is always a difficult one, and when the hole is deep is seldom altogether successful. But in most cases a large proportion of the tubing may be recovered if suitable means are employed. These means consist of tools for disconnecting and lifting the several lengths of tubing, or for lifting them altogether.

Of the former kind, the simplest and most effective is the screw-plug. This instrument consists of a conical plug having its lower end slightly less in diameter than the bore of the tube, and its upper end slightly greater, and provided with a left-handed steeled screw-thread. This plug terminates upwards in a shank and screw-socket for the purpose of fixing it to the rods. The latter, which are constructed specially for this purpose, are of large section, and are connected by left-handed screw-joints. The screw-plug is lowered at the end of these rods into the end of the tube, and turned slowly round till the thread has bitten. When the plug has obtained a firm hold of the tube, the latter will be unscrewed by the continued left-handed motion of the former, and may be lifted by it. The same operation is repeated for each length of tubing.

Of the tools designed to lift the whole length of tubing, the best is that known as "Kind's plug," Fig. 123, from its having been first employed by Kind. It consists of a block of oak of an ovoid form fixed upon the end of an iron rod. This rod passes through the centre of the plug, which it holds by means of a nut, and terminates upwards in a screw-plug for the purpose of attaching it to the ordinary boring rods. The diameter of this wooden plug at its largest part is slightly less than that of the tube, so that a little amount of play is allowed between it and the sides of the tube. When it is required to raise the tubes, the plug is lowered to the desired depth, and one or two shovelsful of coarse, gravelly sand, washed and sifted, are thrown down upon it. This sand fills the space between the sides of the tubing and the plug, and the latter is thereby firmly wedged in. The rods being then hauled up, the tubing is raised with them. If it be desired to make the plug leave go its hold on the tube, it is only necessary to lower it below the lining, when the sand will run out.

When the tubing is too firmly held by the friction against the sides of the bore-hole to allow of it being raised altogether, and it is deemed undesirable to have recourse to the special rods required for the screw-plug, Kind's plug may be used in conjunction with another kind of tool to raise the tubing in portions. The use of the latter tool is to cut through the lining so as to divide it into portions capable of being raised at once. Numerous forms of tools have been invented for this purpose. One of the simplest of these is that represented in Figs. 122 and 125. By suspending this tool at

the requisite and fixed height in the bore-hole, on the end of the boring rods, and turning it round, the cutting edge, which is pressed by a spring against the sides of the hole, cuts through the lining, the severed portions of which may then be raised by Kind's plug in the manner described above. The cutter is so constructed that it may be readily withdrawn from the cut and raised to surface.

Tubing and Testing Oil Wells.—In boring for oil it becomes necessary to shut back the water contained in the overlying strata. This end is readily attained by what is called the "seed-bag" contrivance. When the boring has passed through the water-bearing beds, and a short distance into the underlying impervious stratum, a tube a little less in diameter than the bore-hole is put down, having the "seed-bag" attached to its lower end. This seed-bag is a tube of stout leather, from 4 to 6 feet in length, the inner diameter of which is that of the bore-hole. This bag is passed over the tube, and its lower end lashed fast, the annular space between the tube and the bag is then filled tight with flax seed, and the upper end of the bag lashed fast to the tube in the same way as the lower end. The bag is thus made to fit the bore-hole accurately. When it has been lowered into its position, the moisture in a little time causes the seed to swell, and to effectually close the passage against both the water from above and the gas and oil from below. The boring is then continued through the tube. Recently a "water-packer," which is a kind of cup-leather arrangement, has been introduced as a substitute for the seed-bag.

When an oil well has been bored to the required depth, it is tubed for testing and pumping. The tubing used for this purpose consists generally of 2-inch wrought-iron pipe; it is in lengths of from 12 to 15 feet, which are screwed together by means of a thread on each end and a close-fitting thimble. The working or pump barrel is screwed on to this tubing and lowered into the well. The barrel, usually of brass, is from 5 to 6 feet in length, and has a bore of $1\frac{3}{4}$ inch or $1\frac{7}{8}$ inch, always less than that of the tubing. In the lower end, is placed the bottom valve, or, as it is usually called, the "standing box." The working barrel having been attached to the first length of tube, in the same way as the several lengths are attached one to another, and a swivel-head screwed on to the other end; this first length is suspended by tackle blocks from the boring frame, and lowered by the same processes as those already described for boring rods. The clamps, which are used in place of the "nipping fork," are placed across the mouth of the driving pipe under the thimble at the end of the joint, made to close tightly, and held by a ring at the end of the handles. The swivel is then taken off by means of the pipe tongs, another length of tubing is attached, and the swivel-head having been replaced, the lowering is proceeded with as before. These operations are continued until the bottom of the well has been nearly reached. The pump-rods, called sucker-rods, are of wood, ash or hickory; they are in lengths of 24 feet, and are $1\frac{1}{2}$ inch in diameter. The "sucker" or working valve is attached to the end of one of these lengths, and the whole is lowered in the same manner as the tubing till the valve goes into the working barrel. The several lengths of rod are provided with a thread, and connected together by means of a thimble, like the tubes. The rods are attached to the working beam, Figs. 50 and 51, by a rod, which passes through a stuffing box on the end of the tubing, above the driving pipe. The operation of pumping is performed by the engine in the same way as that of drilling the bore-hole. It will be observed that the pumps can be readily taken out of the well.

Special Systems of Boring.—Improvements effected in the mechanical appliances used in boring have led to the introduction and establishment of special systems whereby rapidity of execution is gained. Another advantage which these systems aim at securing is the possibility of extracting the

rock in the form of a solid core without having recourse to extraordinary and slow means. The advantages accruing from rapidity of execution and the extraction of solid cores are very great, and hence the system which renders such advantages obtainable is of very great importance and value; as an offset against these merits, however, such systems involve complexity of parts. The appliances required by the ordinary methods of boring are few and extremely simple; they are such as anyone may readily obtain for oneself, and use without much special knowledge. But the systems in question require more or less complicated erections, and the attention of trained and experienced workmen.

Two systems of a special character have come into common use, and are known respectively as "Mather and Platt's system," and the "Diamond system." The former of these is less special in the character of its appliances than the latter, and demands, therefore, fuller description and illustration. The essential principle of Mather and Platt's system consists in the substitution of a flat hempen or wire rope for the iron rods employed in the ordinary methods. By this means, a great saving of time is effected in raising and lowering the cutting tools, the operations being performed as rapidly as those of raising and lowering the sludger. The appliances introduced, and the methods of working adopted to render such a substitution possible, as well as other and minor advantages claimed for the system, will be best understood from the following description, given by Mr. Mather in a paper read before the Institution of Mechanical Engineers:

Mather and Platt's System of Boring.—The distinctive peculiarities of this method of boring consist in the means adopted for giving the percussive and rotary actions to the boring tool; and also in the construction of the tool or boring head, and of the shell pump for clearing out the hole after the action of the boring head. Instead of these implements being attached to rods, they are suspended by a flat hemp rope, about $\frac{1}{2}$ inch thick and $4\frac{1}{2}$ inches broad, such as is commonly used at collieries; and the boring tool and shell pump are raised and lowered in the bore-hole as quickly as the buckets and cages in a colliery shaft. The following is a description of the construction and the methods of working this machine: The flat rope A, Fig. 128, from which the boring head B is suspended, is wound upon a large drum C, which is driven by a steam engine B having a reversing motion, so that one man can regulate the operation with the greatest ease. This winding drum is 10 feet in diameter in the large machine, and is capable of holding 3000 feet length of rope $4\frac{1}{2}$ inches broad and $\frac{1}{2}$ inch thick. All the working parts are fitted into a wood and iron framing E, thus rendering the whole a compact and complete machine. On leaving the drum C, the rope passes under a guide pulley F, and then over a large pulley G carried in a fork at the top of the piston rod of a vertical single-acting steam cylinder H; this cylinder, by which the percussive action of the boring head is produced, is shown to a larger scale in the vertical sections, Figs. 130 and 131. In the larger size of machine here shown, the cylinder is fitted with a piston of 15 inches diameter, having a heavy cast-iron rod 7 inches square, which is made with a fork at the top carrying the flanged pulley G of about 3 feet diameter, and of sufficient breadth for the flat rope A to pass over it. The boring head having been lowered by the winding drum to the bottom of the bore-hole, the rope is fixed secure at that length by the clamp J; steam is then admitted underneath the piston in the cylinder H by the steam valve K, and the boring tool is lifted by the ascent of the piston rod and pulley G; and on arriving at the top of the stroke the exhaust valve L is opened for the steam to escape, allowing the piston rod and carrying pulley to fall freely with the boring tool, which falls with its full weight to the bottom of the bore-hole. The exhaust port being 6 inches above the

bottom of the cylinder, while the steam port is situated at the bottom, there is always an elastic cushion of steam retained in the cylinder for the piston to fall upon, thus preventing the piston from striking the bottom of the cylinder. The steam and exhaust valves are worked with a self-acting motion by the tappets M M, which are actuated by the movement of the piston rod; and a rapid succession of blows is thus given by the boring tool on the bottom of the bore-hole. As it is necessary that motion should be given to the piston before the valves can be acted upon, a small jet of steam N is allowed to be constantly blowing into the bottom of the cylinder; this causes the piston to move slowly at first, so as to take up the slack of the rope and allow it to receive the weight of the boring head gradually and without a jerk. An arm attached to the piston rod then comes in contact with a tappet, which opens the steam valve K, and the piston rises quickly to the top of the stroke; another tappet worked by the same arm then shuts off the steam, at the same time the exhaust valve L is opened by a corresponding arrangement on the opposite side of the piston rod. By shifting these tappets, the length of stroke of the piston can be varied from 1 to 3 feet according to the material to be bored through; the height of fall of the boring head at the bottom of the bore-hole being double the length of the piston stroke. The fall of the boring head and piston can also be regulated by a weighted valve on the exhaust pipe, checking the escape of the steam, so as to cause the descent to take place slowly or quickly as may be desired.

The boring head B, Fig. 128, is shown to a larger scale in Figs. 132 to 135, and consists of a wrought-iron bar about 4 inches diameter and 8 feet long, to the bottom of which a cast-iron cylindrical block *a* is secured. This block has numerous square holes through it, into which the chisels or cutters *b*, of which two different arrangements are shown, are inserted with tapered shanks, so as to be very firm when working, but at the same time easily taken out for repairing and sharpening. A little above the block *a*, another cylindrical casting *c* is fixed upon the bar B, which acts simply as a guide to keep the bar perpendicular. Higher still is fixed a second guide *d*; but on the circumference of this are secured cast-iron plates made with ribs of a saw-tooth or ratchet shape, catching only in one direction. These ribs are placed at an inclination like segments of a screw-thread of very long pitch, so that, as they bear against the rough sides of the bore-hole when the bar is raised or lowered, they assist in turning it, for causing the cutters to strike in a fresh place at each stroke. Each alternate plate has the projecting ribs inclined in the opposite direction, so that one half of the ribs are acting to turn the bar round in rising, and the other half to turn it in the same direction in falling. These projecting spiral ribs simply assist in turning the bar, and immediately above the upper guide *d* is the arrangement by which the definite rotation is secured. To effect this object two cast-iron collars, *e* and *f*, are cottered fast to the top of the bar B, and placed about 12 inches apart. The upper face of the lower collar *e* is formed with deep ratchet-teeth of about 2 inches pitch, and the under face of the top collar *f* is formed with similar ratchet-teeth, set exactly in line with those on the lower collar. Between these collars, and sliding freely on the neck of the boring bar B, is a deep bush *g*, which is also formed with corresponding ratchet-teeth on both its upper and lower faces; but the teeth on the upper face are set half a tooth in advance of those on the lower face, so that the perpendicular side of each tooth on the upper face of the bush is directly above the centre of the inclined side of a tooth on the lower face. To this bush is attached the wrought-iron bow *h*, by which the whole boring bar is suspended with a hook and shackle O, Fig. 132, from the end of the flat rope A. The rotary motion of the bar is obtained as follows: When the boring tool falls and strikes the bow, the lifting bush *g*, which during the lifting has been engaged with the ratchet-teeth

of the top collar f, falls upon those of the bottom collar e, and thereby receives a twist backwards through the space of half a tooth; and on commencing to lift again, the bush rising up against the ratchet-teeth of the top collar f receives a further twist backwards through half a tooth. The flat rope is thus twisted backwards to the extent of one tooth of the ratchet, and during the lifting of the tool it untwists itself again, thereby rotating the boring tool forwards through that extent of twist between each successive blow of the tool. The amount of this rotation may be varied by making the ratchet-teeth of coarser or finer pitch. The motion is entirely self-acting, and the rotary movement of the boring tool is ensured with mechanical accuracy. This simple and most effective action taking place at every blow of the tool produces a constant change in the position of the cutters, thus increasing their effect in breaking the rock.

The shell pump, for raising the material broken up by the boring head, is shown in Figs. 136 and 137, and consists of a cylindrical shell or barrel P of cast iron, about 8 feet long and a little smaller in diameter than the size of the bore-hole. At the bottom is a clack a opening upwards, somewhat similar to that in ordinary pumps; but its seating, instead of being fastened to the cylinder P, is in an annular frame c, which is held up against the bottom of the cylinder by a rod a passing up to a wrought-iron bridge e at the top, where it is secured by a cotter f. Inside the cylinder works a bucket b similar to that of a common lift-pump, having an indiarubber disk valve on the top side; and the rod d of the bottom clack passes freely through the bucket. The rod g of the bucket itself is formed like the long link in a chain, and by this link the pump is suspended from the shackle O, at the end of the flat rope, the bridge e preventing the bucket from being drawn out of the cylinder. The bottom clack a is made with an indiarubber disk, which opens sufficiently to allow the water and small particles of stone to enter the cylinder; and in order to enable the pieces of broken rock to be brought up as large as possible, the entire clack is free to rise bodily about 6 inches from the annular frame c, thereby affording ample space for large pieces of rock to enter the cylinder when drawn in by the up stroke of the bucket.

The general working of this boring machine is as follows: When the boring head B is hooked on the shackle O, at the end of the rope A, its weight pulls round the drum and winding engine, and by means of a brake it is lowered steadily to the bottom of the bore-hole; the rope is then secured at that length by screwing up tight the clamp J. The small steam jet N is next turned on, for starting the working of the percussion cylinder H; and the boring head is then kept continuously at work until it has broken up a sufficient quantity of material at the bottom of the bore-hole. The clamp J which grips the rope is made with a slide and screw I, whereby more rope can be gradually given out as the boring head penetrates deeper in the hole. In order to increase the lift of the boring head, or to compensate for the elastic stretching of the rope, which is found to amount to 1 inch in each 100 feet length, it is simply necessary to raise the top pair of tappets on the tappet rods whilst the percussive motion is in operation. When the boring head has been kept at work long enough, the steam is shut off from the percussion cylinder, the rope unclamped, the winding engine put in motion, and the boring head wound up to the surface, where it is then slung from an overhead suspension bar Q, by means of a hook mounted on a roller for running the boring head away to one side, clear of the bore-hole.

The shell pump is next lowered down the bore-hole by the rope, and the debris pumped into it by lowering and raising the bucket about three times at the bottom of the hole, which is readily effected by means of the reversing motion of the winding engine. The pump is then brought up to

the surface, and emptied by the following very simple arrangement: It is slung by a traversing hook from the overhead suspension bar Q, and is brought perpendicularly over a small table R in the waste tank T; and the table is raised by the screw S until it receives the weight of the pump. The cotter *f*, which holds up the clack seating *c* at the bottom of the pump, is then knocked out, and the table being lowered by the screw, the whole clack seating *c* descends with it, as shown in Fig. 128, and the contents of the pump are washed out by the rush of water contained in the pump cylinder. The table is then raised again by the screw, replacing the clack seating in its proper position, in which it is secured by driving the cotter *f* into the slot at the top, and the pump is again ready to be lowered down the bore-hole as before. It is generally necessary for the pump to be emptied and lowered three or four times in order to remove all the material that has been broken up by the boring head at one operation.

The rapidity with which these operations may be carried on is found in the experience of the working of the machine to be as follows: The boring head is lowered at the rate of 500 feet a minute. The percussive motion gives twenty-four blows a minute. This rate of working continued for about ten minutes in red sandstone and similar strata is sufficient for enabling the cutters to penetrate about 6 inches in depth, when the boring head is wound up again at the rate of 300 feet a minute. The shell pump is lowered and raised at the same speeds, but only remains down about two minutes, and the emptying of the pump, when drawn up, occupies from two to three minutes.

In the construction of this machine it will be seen that the great desideratum of all earth boring has been well kept in view, namely, to bore holes of large diameter to a great depth with rapidity and safety. The object is to keep either the boring head or the shell pump constantly at work at the bottom of the bore-hole, where the actual work has to be done; to lose as little time as possible in raising, lowering, and changing the tools; to expedite all the operations at the surface; and to economize manual labour in every particular. With this machine, one man standing on a platform at the side of the percussion cylinder performs all the operations of raising and lowering by the winding engine, changing the boring head and shell pump, regulating the percussive action, and clamping or unclamping the rope; all the handles for the various steam valves are close to his hand, and the brake for lowering is worked by his foot. Two labourers attend to changing the cutters and clearing the pump. Duplicate boring heads and pumps are slung to the overhead suspension bar Q, Fig. 128, ready for use, thus avoiding all delay when any change is requisite.

Solid cores, showing perfectly the nature and the quality of the rock, with the angle of its inclination, and other particulars, are obtained by simply working the boring head with all the inside cutters removed, leaving only the outside circle of cutters and the few cross chisels alternating with them round the circumference of the block; then by continued working a slightly conical core is formed, which may be made longer or shorter according to the length and inclination of the cutters; this core becomes finally jammed fast between the cutters and broken off at the root, and is then brought up to the surface by the boring head. Beautiful specimens of coal have by this means been brought up, large enough to show the quality and dip of the seam.

The boring head while at work may suddenly be jammed fast, either by breaking into a fissure, or in consequence of broken rock falling upon it from loose strata above. All the strain possible is then put upon the rope, either by the percussion cylinder or by the winding engine; and if the rope is an old one or rotten it breaks, leaving perhaps a long length in the hole. The claw grapnel, shown in Fig. 144, Plate XXII., is then attached to the rope remaining on the winding drum, and is

lowered until it rests upon the slack broken rope in the bore-hole. The grapnel is made with three claws A A centered in a cylindrical block B, which slides vertically within the casing C, the tail ends of the claws fitting into inclined slots D in the casing. During the lowering of the grapnel, the claws are kept open, in consequence of the trigger E being held up in the position shown in Fig. 144 by the long link F, which suspends the grapnel from the top rope. But as soon as the grapnel rests upon the broken rope below, the suspending link F continuing to descend allows the trigger E to fall out of it; and then in hauling up again, the grapnel is lifted only by the bow G of the internal block B, and the entire weight of the external casing C bears upon the inclined tail-ends of the claws A, causing them to close in tight upon the broken rope and lay hold of it securely. The claws are made either hooked at the extremity, as in Fig. 144, or serrated, as in Fig. 145. The grapnel is then hauled up sufficiently to pull the broken rope tight, and wrought-iron rods 1 inch square, with hooks attached at the bottom, are let down to catch the bow of the boring head, which is readily accomplished. Two powerful screw-jacks are applied to the rods at the surface, by means of the step-ladder shown in Figs. 148 and 149, in which the cross-pin H is inserted at any pair of the holes, so as to suit the height of the screw-jacks.

If the boring head does not yield quickly to these efforts, the attempt to recover it is abandoned, and it is got out of the way by being broken up into pieces. For this purpose the broken rope in the bore-hole has first to be removed, and it is therefore caught hold of with a sharp hook and pulled tight in the hole, while the cutting grapnel, which is shown in Fig. 146, is slipped over it and lowered by the rods to the bottom. This tool is made with a pair of sharp cutting jaws or knives I I opening upwards, which in lowering pass down freely over the rope; but when the rods are pulled up with considerable force, the jaws nipping the rope between them cut it through, and it is thus removed altogether from the bore-hole. The solid wrought-iron breaking-up bar, shown in Fig. 150, which weighs about a ton, is then lowered, and by means of the percussion cylinder it is made to pound away at the boring head, until the latter is either driven out of the way into one side of the bore-hole, or broken up into such fragments as that partly by the shell pump and partly by the grapnels the whole obstacle is removed. The boring is then proceeded with again, the same as before the accident.

The same mishap may occur with the shell pump getting jammed fast in the bore-hole, and the same means of removing the obstacle are then adopted. Experience has shown the danger of putting any greater strain upon the rope than the percussion cylinder can exert; and it is therefore usual to lower the grapnel rods at once, if the boring head or pump gets fast, thus avoiding the risk of breaking the rope. Such accidents are, however, not of frequent occurrence.

The breaking of a cutter in the boring head is not an uncommon occurrence. If, however, the bucket grapnel, Figs. 141 to 143, or the small screw grapnel, Fig. 147, be employed for its recovery, the hole is readily cleared without any important delay. The screw grapnel, Fig. 147, is applied by means of the iron grappling rods, so that by turning the rods the screw works itself round the cutter or other similar article in the bore-hole, and securely holds it while the rods are drawn up again to the surface. The bucket grapnel, shown in Figs. 141 to 143, is also employed for raising clay, as well as for the purpose of bringing up cores out of the bore-hole, where these are not raised by the boring head itself in the manner already described. The action of this grapnel is nearly similar to that of the claw grapnel, Fig. 144; the three jaws A A, hinged to the bottom of the cylindrical casing C, and attached by connecting rods to the internal block B sliding within the casing

C, are kept open during the lowering of the tool, the trigger E being held up in the position shown in Fig. 141 by the long suspending link F. On reaching the bottom, the trigger is liberated by the further descent of the link F, which, in hauling up again, lifts only the bow G of the internal block B; so that the jaws A are made to close inwards upon the core, which is thus grasped firmly between them and brought up within the grapnel. A large number of specimens of cores are exhibited of about 3 inches diameter, which have been brought up by this grapnel from different bore-holes. Where there is clay or similar material at the bottom of the bore-hole, the weight of the heavy block B in the grapnel causes the sharp edges of the pointed jaws to penetrate to some depth into the material, a quantity of which is thus enclosed within them and brought up.

Another grapnel that is also used where a bore-hole passes through a bed of very stiff clay is shown in Figs. 138 to 140, and consists of a long cast-iron cylinder H fitted with a sheet-iron mouthpiece K at the bottom, in which are hinged three conical steel jaws J J opening upwards. The weight of the tool forces it down into the clay with the jaws open; and then on raising it, the jaws having a tendency to fall, cut into the clay and enclose a quantity of it inside the mouthpiece, which on being brought up to the surface is detached from the cylinder H and cleaned out. A second mouthpiece is put on and sent down for working in the bore-hole while the first is being emptied, the attachment of the mouthpiece to the cylinder being made by a common bayonet-joint L, so as to admit of readily connecting and disconnecting it.

The tubes used for lining the bore-hole are of cast iron, varying in thickness from $\frac{5}{8}$ to 1 inch according to their diameter, and all of 9 feet in length. The successive lengths are connected together by means of wrought-iron covering hoops 9 inches long made of the same outside diameter as the tube, so as to be flush with it. These hoops are from $\frac{1}{4}$ to $\frac{3}{8}$ inch thick, and the ends of each tube are reduced in diameter by turning down for $4\frac{1}{2}$ inches from the end, to fit inside the hoops. A hoop is shrunk fast on one end of each tube, leaving $4\frac{1}{2}$ inches of socket projecting to receive the end of the next tube to be connected. Four or six rows of screws with countersunk heads, placed at equal distances round the hoop, are screwed through into the tubes to couple the two lengths securely together. Thus a flush joint is obtained both inside and outside the tubes. The lowest tube is provided at the bottom with a steel shoe, having a sharp edge for penetrating the ground more readily.

In small borings, from 6 to 12 inches diameter, the tubes are inserted into the bore-hole by means of screw-jacks, by the simple and inexpensive method shown in Figs. 153 and 154, Plate XXII. The boring-machine foundation A A, which is of timber, is weighted at B B by stones, pig iron, or any available material; and two screw-jacks C C, each of about 10 tons power, are secured with the screws downwards, underneath the beams D D crossing the shallow well E, which is always excavated at the top of the bore-hole. A tube F having been lowered into the mouth of the bore-hole by the winding engine, a pair of deep clamps G are screwed tightly round it, and the screw-jacks acting upon these clamps force the tube down into the ground. The boring is then resumed, and as it proceeds the jacks are occasionally worked, so as to force the tube if possible even ahead of the boring tool. The clamps are then slackened and shifted up the tubes, to suit the length of the screws of the jacks; two men work the jacks and couple the lengths of tubes as they are successively added. The actual boring is carried on simultaneously within the tubes, and is not in the least impeded by their insertion, which simply involves the labour of an additional man or two.

In the event of any accident occurring to the tubes while they are being forced down the bore-hole, such as requires them to be drawn up again out of the hole, the prong grapnel shown in Fig. 151, Plate XXII., is employed for the purpose, having three expanding hooked prongs, which slide down readily inside the tube, and spring open on reaching the bottom; the hooks then project underneath the edge of the tube, which is thus raised on hauling up the grapnel. In case the tubes get disjointed and become crooked during the process of tubing, the long straightening plug shown in Fig. 152 is lowered down inside them, consisting of a stout piece of timber faced with wrought-iron strips; above this is a heavy cast-iron block, the weight of which forces the plug past the part where the tubes have got displaced, and thereby straightens them again.

THE DIAMOND SYSTEM.—The diamond system differs essentially in principle from every other method of rock boring. We have already shown that the percussive action invariably attributed to the common boring tools was rendered necessary by the difference of hardness between the cutting tool and the rock being in favour of the latter. The inventor of the diamond drill sought to reverse this condition by employing for the cutting tool the hardest known substance, namely, the diamond, and thereby to remove the necessity for the percussive action. The costly character of the material would, however, have precluded the practicability of the idea had it existed only in the form in which it is used as a gem. But fortunately it is found in comparative abundance in an imperfectly crystallized form known as "carbonate." This carbonate, which until recently had but little commercial value, is of a dull black colour, and is characterized by little or no cleavage. This latter quality is a very valuable one, as it removes the liability to split, to which the more perfect variety is exposed. But although the carbonate is much harder than the rock to be pierced, it could not be made to cut the latter by means of a cutting edge after the manner of steel instruments, and therefore another mode of applying it had to be discovered. It is a well-known fact, that when two substances of unequal hardness are rubbed together, the softer is worn away by the friction; this action of abrasion was chosen as that through which the diamond could be made to act most effectively in piercing rock. Thus, in the diamond system of boring, the rock is worn down by abrasion; and though such a process may appear at first sight a slow one, experience has shown that when effected with suitable appliances, it is, on the contrary, far more rapid than the ordinary process of fracture by blows from a falling tool.

In applying the diamond to rock drilling, a number of the stones are set in the edge of a steel cylinder or crown, to which the rods are attached. To fasten the stones in securely, holes are made in the metal just sufficiently large to receive them, and the metal is hammered over so as to bury them, leaving each stone only the amount of projection necessary to enable it to rest upon the rock, and to allow the debris and water to pass beneath the crown. The setting of the stones needs to be done with care, for the greatest danger to the drill arises from the liability of the stones to come out. The wear of the stones even in hard rock is trifling; but the loosening of one of them, besides occasioning trouble and loss, is a source of danger to the others. As the stones are set in a ring, the minimum amount of work is performed, for the work of abrasion by the stones is required only to form an annular space, and not to remove the rock within the circumference of the bore-hole, as in other systems. When this annular space has been cut, the solid core may be extracted, and the advantage gained thereby is not merely an economy of labour, but the obtaining of clear and positive evidence concerning the character of the strata passed through. Indeed, the chief merit

of the diamond system, great as that of expeditious execution may be, consists in its bringing out the core of the bore-hole solid, instead of in the powdered state to which it is reduced by other systems.

The crown in which the diamonds are set is screwed on to the end of steel tubes, which serve as rods for transmitting the motion from the surface. These tubes or hollow rods terminate at their upper extremity in a universal clutch, which allows them to turn, and which is connected with a cross-head sliding between two vertical uprights. To keep the bore-hole truly vertical, these need to be very carefully set and fixed. A rotary motion is communicated to the rods from a steam engine, by means of suitable gearing. The speed of rotation is usually about 250 revolutions a minute. The weight upon the crown is made to vary, according to the hardness of the rock and the rate of progress required, from 400 lbs. to 800 lbs., which weight is furnished by the rods, increased by a weight, or diminished by a counterweight, according to the depth attained. During the progress of the boring, water is forced down the hollow rods to remove the debris from the annular space in which the diamonds are working, and to keep the latter cool. The core, when formed, passes into a core-tube, in which it is held, on the rods being withdrawn, by sliding wedges or clips. Suitable gearing of an ordinary character is provided for raising and lowering the rods; and for remedying accidents the common appliances are made use of.

The diamond drill will cut through the hardest rock, even emery having been pierced at the rate of 2 inches a minute. The ordinary rate of progress during the actual boring is stated to be from 2 inches to 3 inches a minute in granite and the hardest limestones, 1 inch a minute in quartz, and 4 inches a minute in sandstone. These are the speeds attained in ordinary practice. In soft strata, such as clay and sand, the diamond cutter is of no use whatever. When these strata are met with, the ordinary tools are employed until hard rock is reached.

The diamond drill, as now used for deep borings, will be found illustrated on Plate XXIII.

CHAPTER II.

EXCAVATING MACHINERY.

Excavating machines naturally constitute a very important class among those which are used for mining purposes. More rapidly, perhaps, than any other, this class has developed itself within the past few years. From consisting of a few simple hand-tools that had been in use from time immemorial, it has come to include various complex machines, the invention of which has given new life to many languishing undertakings, and a great impetus to the mining industry generally. In the present chapter, the most important of those machines will be described and illustrated. But as for some kinds, rock-borers for example, there exist numerous machines, differing one from another only in the details of their construction, description will be confined to those which possess a markedly distinctive and typical character.

Hand Rock-boring Tools.—Hand-boring tools consist essentially of the drill and the hammer, or the sledge. The drill is an iron or a steel rod terminating at one end in a cutting edge, and at the other end in a flat face to receive the blow from the hammer. Thus the parts of a rock-drill are the *bit* or chisel edge, the *stock*, and the *striking face*. Formerly the stock was always of iron, but now it is usual to make the whole drill of cast steel, the superior solidity of texture in steel rendering it capable of transmitting the force of a blow more effectively than iron. The cutting edge of a drill demands careful consideration. To enable the tool to free itself well in the bore-hole, and also to avoid introducing unnecessary weight into the stocks, the bit is made wider than the latter; the difference in width may be as much as one inch. It is evident that in hard rock the liability of the edge to fracture increases as the difference of width. The edge of the drill may be straight, as in the flat chisel for deep boring, or slightly curved. The straight edge cuts its way somewhat more freely than the curved, but it is weaker at the corners than the curved, a circumstance which renders it less suitable for very hard rock. It is also slightly more difficult to forge. Figs. 162 and 163 show the straight and curved bits, and the angles of the cutting edges for use in rock. The width of the bit varies, according to the size of the hole required, from 1 inch to $2\frac{1}{2}$ inches.

The stock is octagonal in section, and is made in lengths varying from 20 inches to 42 inches. The shorter the stock, the more effectively does it transmit the blow, and therefore it is made as short as possible; for this reason several lengths are employed in boring a blast-hole, the shortest being used at the commencement of the hole, a longer one to continue the depth, and a still longer one, sometimes, to complete it. To ensure the longer drills working freely in the hole, the width of the bit should be very slightly reduced in each length. It has already been remarked that the diameter of the stock is less than the width of the bit; this difference may be greater in coal drills than in

rock or "stone" drills; a common difference in the latter is $\frac{3}{8}$ of an inch for the smaller sizes, and from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch for the longer. The following proportions may be taken as the average adopted:

Width of the Bit.	Diameter of the Stock.	Width of the Bit.	Diameter of the Stock.
1 inch	$\frac{5}{8}$ inch.	$1\frac{3}{4}$ inch	$1\frac{1}{8}$ inch.
$1\frac{1}{8}$ "	$\frac{3}{4}$ "	2 inches	$1\frac{3}{8}$ "
$1\frac{1}{4}$ "	$\frac{7}{8}$ "	$2\frac{1}{4}$ "	$1\frac{1}{2}$ "
$1\frac{1}{2}$ "	1 "	$2\frac{1}{2}$ "	$1\frac{5}{8}$ "

The striking face of the drill should be flat. The diameter of the face is less than that of the stock in all but the smallest sizes, the difference being made by drawing in the striking end. The amount of reduction is greater for the larger diameters, that of the striking face being rarely more than $\frac{7}{8}$ of an inch.

Sledges and hammers are important tools in the hands of the miner. The distinction between a sledge and a hammer is founded on dimensions only; the hammer being intended for use in *one* hand, is made comparatively light, and is furnished with a short handle; while the sledge, being intended for use in *both* hands, is furnished with a much longer handle, and is made heavier. Sledges are used for striking the drill in boring blasting holes, for driving wedges in rock and in coal, and for breaking up large masses of the latter. The blasting sledge and the wedge-driving sledge being employed under different conditions, require different forms and dimensions. The striking face of the blasting sledge should be flat, to enable the striker to deliver a direct blow with certainty upon the head of the drill; and to facilitate the directing of the blow, as well as to increase its effect, the mass of metal composing the head should be concentrated within a short length. To cause the sledge to fly off from the head of the drill in the case of a false blow being struck, and thereby to prevent it from striking the hand of the man who holds the drill, the edges of the striking face should be chamfered or bevelled down till the diameter is reduced by nearly one-half. This requirement is, however, but seldom provided for. When used for wedge driving, the head of the sledge is very frequently required to follow the wedge into the cleft, and to enable it to do this, the head must be made long and of small diameter, that is, the mass of metal composing the head must be distributed throughout a greater length. The striking face should be rather convex than flat to avoid a sharp edge, which would soon be battered off by coming into contact with the edges of the rocks in the cleft. A longer handle or helve is also needed for the wedge-driving than for the blasting sledge.

The head of a sledge is of iron; it consists of a pierced central portion called the eye, and two shanks or "stumps," the steeled ends of which form the striking faces or "panes." The form of the head varies in different localities, but whatever the variation may be, the form may be classed under one of four types or "patterns." A very common form is that shown in Fig. 165, and known as the "Bully" pattern. By varying the width, as shown in Fig. 166, we obtain the "broad bully," the former being called for the sake of distinction the "narrow" bully. Another common form is the "Pointing" pattern, represented in Fig. 167. The form shown in Fig. 168 is designated as the "Bloat" pattern; and that given in Fig. 169 the "Plug" pattern. Each of these forms possesses peculiar merits which render it more suitable for certain uses than the others. The same forms are used for hammers. The eye is generally made oval in shape, but sometimes, especially with the bloat pattern, it is made circular, as shown in Fig. 168. The weight of a sledge head may vary from 5 lbs. to 10 lbs., but a common and convenient weight is 7 lbs. The length of the helve varies from 20 inches to

30 inches; a common length is 24 inches for blasting, and 28 inches for wedge-driving sledges. The average weight of hammer heads is about 3 lbs., and the average length of the helve 10 inches.

All the forms of sledge heads may be used for wedge-driving purposes, but that which is generally employed, especially for coal wedging, is the pointing pattern. The modification made in the form illustrated is merely in the length of the head. A common length of a coal-wedging sledge is 12 inches, with a diameter of about $2\frac{1}{4}$ inches in the thickest part. The stumps are tapered down to about $1\frac{1}{2}$ inch at the panes, and the angles of the stumps are taken off by a chamfer beginning near the eye and gradually increasing to form an octagonal section at the panes.

Fig. 170 represents a blasting sledge used in South Wales. The stumps are octagonal in section, and spring from a square block in the centre. The panes or striking faces, however, are circular and flat. The length of the head is $8\frac{3}{4}$ inches, that of the helve 27 inches, and the weight of the tool complete 7 lbs.

Fig. 171 represents a blasting sledge used in North Wales. The central block is an irregular octagon in section, formed by slightly chamfering the angles of a square section, and the stumps are chamfered down to form a regular octagon at the panes, which are flat. The length of the head is $7\frac{3}{4}$ inches, that of the helve 22 inches, and the weight of the tool complete 6 lbs. 7 oz.

The sledges used in the north of England have shorter heads, and are lighter than the foregoing. Fig. 172 represents one of these blasting sledges. The head is nearly square in section at the centre, and the panes are flat. The length of the head is 5 inches, that of the helve $24\frac{1}{2}$ inches, and the weight of the sledge complete 4 lbs. 14 oz.

Drills, as before remarked, are used in sets of different lengths. The sets may be intended for use by one man or by two. In the former case, the sets are described as single-hand sets, and they contain a hammer for striking the drills; in the latter case, the sets are spoken of as double-handed, and they contain a sledge instead of a hammer for striking.

Besides the drill and the hammer, other auxiliary tools are used in preparing the hole for the blasting charge. If the bore-hole is inclined downwards, the debris or bore-meal made by the drill remains at the bottom of the hole, where it is converted into mud or "sludge" by the water there present. This sludge, as in the case of deep boring, has to be removed as the work progresses, to keep the rock exposed to the action of the drill. The removal of the sludge is effected by a simple tool called a "scraper," Fig. 177. It consists of a rod of iron from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch in diameter, and of sufficient length to reach the bottom of the bore-hole. One end of the rod is flattened out on the anvil and made circular in form, and then turned up at right angles to the stem. The disc thus formed must be less in diameter than the bore-hole, to allow it to pass readily down. When inserted in the hole, the scraper is turned round while it is being pressed to the bottom; on withdrawing the instrument, the sludge is brought up upon the disc. This operation, two or three times repeated, is sufficient to clear the bore-hole. The other end of the scraper is sometimes made to terminate in a ring for convenience in handling. Instead of the ring, however, at one end, a disc may be made at each end, the discs in this case being of different diameter, to render the scraper suitable for different size bore-holes. Sometimes the scraper is made to terminate in a spiral hook or "drag twist." The use of the drag is to thoroughly cleanse the hole before inserting the charge. A wisp of hay is pushed down the hole, and the drag end of the scraper introduced after it, and turned round till it has become firmly entangled. The withdrawal of the hay by the drag wipes the bore-hole clean. Instead of the twist drag, the "loop" drag is frequently employed. This consists of a loop or eye, through

which a piece of rag or tow is passed. The rag or tow is used for the same purpose as the hay, namely, to thoroughly cleanse and dry the bore-hole previous to the introduction of the charge.

When the charge has been placed in the bore-hole, and the fuse laid to it, the hole needs to be tamped, that is, the portion above the charge has to be filled up with some suitable substance. For this purpose, a rammer, stemmer, or tamping iron, as the instrument is variously called, is required. This instrument is illustrated in Fig. 178. It consists of a metal bar, the tamping end of which is grooved to receive the fuse lying against the side of the bore-hole. The other end is flat, to afford a pressing surface for the hand, or a striking face for the hammer when the latter is needed. To prevent the danger of accidental ignition from sparks caused by the friction of the metal against silicious substances, the employment of iron stemmers has been prohibited by law. They are usually made of copper, or of phosphor-bronze, the latter substance being more resisting than the former.

Sometimes in wet ground it becomes necessary to shut back the water from the bore-hole before introducing the charge of gunpowder. This happens very frequently in shaft sinking. The method employed in such cases is to force clay into the interstices through which the water enters. The instrument used for this purpose is the "claying iron" or "bull," represented in Fig. 184. It consists of a round bar of iron, called the stock or shaft, a little smaller in diameter than the bore-hole, and a thicker portion, called the head or pole, terminating in a striking face. The lower end of the shaft is pointed to enable it to penetrate the clay, and the head is pierced by a hole about an inch in diameter to receive a lever.

Clay in a plastic state having been put into the bore-hole, the bull is inserted and driven down by blows with the sledge. As the shaft forces its way down, the clay is driven into the joints and crevices of the rock on all sides. To withdraw the bull, a bar of iron is placed in the eye, and used as a lever to turn it round to loosen it; the rod is then taken by both hands, and the bull lifted out. To allow the bull to be withdrawn more readily, the shaft should be made with a slight taper, and kept perfectly smooth. As the bull is subjected to a good deal of heavy hammering on the head, the latter part should be made stout. This tool, which should be considered as an extra instrument rather than as an essential part of a blasting set, is a very serviceable one, and should always be at hand in wet ground when gunpowder is employed.

Another instrument of this auxiliary character is the beche, Fig. 192, used for extracting a broken drill. It consists of an iron rod of nearly the diameter of the bore-hole, and hollow at the lower end. The form of the aperture is slightly conical, so that the lower end may easily pass over the broken stock of the drill, and being pressed down with some force, may grasp the stock in the higher portion of the aperture with sufficient firmness to allow of the two being raised together. When only a portion of the bit remains in the hole, it may often be extracted by means of the drag-twist end of the scraper.

On Plate XXVI. will be found three sets of blasting gear: a set of coal-blasting gear; a set of single-hand stone-blasting gear; and a set of double-hand stone-blasting gear. In the first set, the drill shown in Fig. 174 is 22 inches in length; the cutting edge is straight and $1\frac{1}{2}$ inch wide, and the weight is $2\frac{1}{2}$ lbs. The other drill, Fig. 175, is 42 inches in length; it has a straight cutting edge $1\frac{7}{16}$ inch wide, and weighs 4 lbs. 10 oz. The hammer used in this set, and shown in Fig. 176, weighs 2 lbs. 14 oz.; the length of the head is $4\frac{1}{2}$ inches, and that of the handle $7\frac{3}{4}$ inches. In the second, or single-hand stone set, the shorter drill, Fig. 179, is 22 inches in length; the cutting edge is strongly curved, and is $1\frac{1}{2}$ inch in width, and the weight is 3 lbs. 10 oz. The longer drill, Fig. 180,

is 36 inches in length; the width of the cutting edge, which is curved as in the shorter drill, is $1\frac{7}{16}$ inch, and the weight is 6 lbs. 5 oz. The hammer used with this set, and represented in Fig. 181, weighs 3 lbs. 6 oz.; the length of the head is 5 inches, and that of the handle 10 inches. In the third, or double-hand stone set, the first or shortest drill, Fig. 185, is 18 inches in length, $1\frac{3}{4}$ inch wide on the cutting edge, and weighs $4\frac{1}{4}$ lbs. The second drill, Fig. 186, is 27 inches in length, $1\frac{11}{16}$ wide on the cutting edge, and weighs 6 lbs. The third, or longest drill, Fig. 187, is 40 inches in length, $1\frac{5}{8}$ inch wide on the cutting edge, and weighs $9\frac{1}{4}$ lbs. The cutting edges of all these drills are strongly curved, as in the preceding set. The sledge used with this set, and represented in Fig. 188, weighs about 5 lbs.

Machine Rock-Drills.—The most remarkable advance which, in recent, or perhaps in any, times, has been made in the practice of mining, consists in the substitution of machine for hand labour in rock boring. The importance of this change is obvious, and very great. Not only is the miner relieved thereby of the labour of boring, but the speed with which the shot-holes may be bored is increased a hundredfold. This gain of speed offers many practical advantages. The ability to sink a shaft or to drive a heading rapidly may ensure the success of an undertaking, and save indirectly the expenditure of large sums of money; and in all cases it allows the time spent in preparatory work to be materially shortened. Indeed it would be difficult to over-estimate the magnitude of the advantage accruing from the increased rate of progress due to the substitution of machine power for hand labour, and in the future we may expect to see its application greatly extended. In making this substitution, numerous difficulties have had to be overcome, and in encountering these many failures have had to be recorded. But it must now be conceded by the most prejudiced that rock-boring machines have successfully passed through what may be described as the tentative stage of their existence, and have taken a foremost place among the mechanical appliances which experience has shown to be capable of effectually performing the work required of them. In the author's work on 'Mining Engineering,' the requirements of a rock drill will be found fully discussed, and the principles and the construction of the most important machine now in use carefully explained and described. In the present work, on account of the great number of machines lately introduced that differ one from another only in the details of their construction, description will be limited to those machines which have a distinctive character, and which have been commonly adopted in England, America, Germany, and France. For the purpose of comparison, the machines are selected of a size suitable for boring a hole $1\frac{1}{2}$ inch in diameter.

Machine drills penetrate rock in the same way as the ordinary hand drills already described, namely, by means of a percussive action. The cutting tool is, in most cases, attached directly to the piston rod, with which it consequently reciprocates. Thus the piston with its rod is made to constitute a portion of the cutting tool, and the blow is then given by the direct action of the steam or the compressed air upon the tool. As no work is done upon the rock by the back stroke of the piston, the area of the forward side is reduced to the dimensions necessary only to lift the piston, and to overcome the resistance due to the friction of the tool in the bore-hole. The piston is made to admit steam or air into the cylinder, and to cut off the supply and to open the exhaust as required, by means of tappet valves, or other suitable devices; and provision is made to allow, within certain limits, a variation in the length of the stroke. During a portion of the stroke, means are brought into action to cause the piston to rotate to some extent, for the purposes that have been already explained. To keep the cutting edge of the tool up to its work, the whole machine is moved forward

as the rock is cut away. This forward or "feed" motion is usually given by hand; but in some cases it is communicated automatically. The machine is supported upon a stand or framing which varies in form according to the situation in which it is to be used. This support is in all cases constructed to allow of the feed motion taking place, and also of the cutting tool being directed at any angle. The support for a rock drill constitutes an indispensable and a very important adjunct to the machine; for upon the suitability of its form, material, and construction, the efficiency of the machine will largely depend.

The foregoing is a general description of the construction and mode of action of percussive rock-drills. The numerous varieties now in use differ from each other, as already remarked, rather in the details of their construction than in the principles of their action, and the importance of the difference is, of course, dependent upon that of the details. It is but just to remark here that the first really practical solution of the rock-drilling problem is due to M. Sommeiller, whose machine was employed in excavating the Mont Cenis Tunnel.

The Dubois-François Rock-Drill.—The design, mode of action, and construction of the Dubois-François rock-drill are founded upon those of Sommeiller's machine; but the improvements effected are of such a character as to render the former greatly superior to the latter. In consequence of this superiority, it has superseded its prototype, and firmly established itself in favour upon the Continent, but especially in Belgium and in France. Its general employment in these two countries, the importance of the work to which it has been applied, and the protracted character of the tests to which it has been subjected, are sufficient evidence of its merits. The design and construction of this machine are shown in Figs. 193 to 196, and its mode of action will be understood from the following description, and the illustration afforded by the drawings.

The percussion piston B reciprocates in a cylinder O. The rod A of this piston is of comparatively large dimensions, and is provided at its lower extremity with an enlarged section pierced to receive the cutting tool. The valve gear is altogether of a special character. An ordinary slide-valve G is connected to two pistons H and H′, each moving in a cylinder provided for it. The piston H′, it must be observed, has a larger surface area than the piston H. When the compressed air enters the valve-chest, it exerts a pressure upon both pistons, which pressure tends to force them in contrary directions. But as the area of H′ is greater than that of H, the pistons, being connected by their rods and the valve, move forward. This motion opens the port x, air is admitted above the piston B, and the drill-bit is driven against the rock. The piston H′, however, is pierced by a small passage i i, which allows the compressed air to pass to the other side of it in J, by which means equilibrium is restored upon the two surfaces. When this equilibrium is established, the action of this piston is destroyed, and, consequently, the pressure acting upon the other piston H, forces the pistons in the contrary direction. This motion opens the port z, air enters below the piston B, and the drill-bit is withdrawn from the rock. To cause this action of the pistons to be repeated, an annular projection C, upon the rod A, comes in contact during the back stroke with a lever D, which, being raised, opens the valve E. The air in the space J escapes, and the equilibrium of the piston H′ is thereby destroyed.

It will be seen that the action of this valve gear throws the motive force suddenly upon the percussion piston for the forward or working stroke, while it affects the return stroke in a less violent manner. The size of the air passage through the valve-piston H′ is a matter of importance. To determine the most suitable proportions, many experiments were needed. If this passage were

too large, equilibrium would be established too soon, and a consequent jerky motion would be produced in the percussion piston; if it were too small, the motion of the latter would be too slow and irregular. The results of experiments have shown that to obtain a perfectly satisfactory action in a machine of the dimensions given in the drawing, the passage should be 0·1 inch in diameter.

The rotation of the drill-bit is obtained by the alternate action of two small pistons P and P′, Fig. 195. These pistons, which are single acting, receive compressed air through the opening *m*, *n* upon the ports of the percussion piston. The alternating action thus obtained is transmitted by a rigid rod Z to a ratchet-wheel V, Fig. 196, fixed upon the rod A, in the fore part of the machine. By this means the rotation of the bit is accomplished in a satisfactory manner at a cost of only a small quantity of air. The feed motion is communicated by hand by means of a screw, as shown in the drawings.

The Ferroux Rock-Drill.—A machine drill, of somewhat novel design, has recently been adopted by the contractor for the construction of the St. Gothard Tunnel, to which work it has been applied with considerable success. It is the invention of M. Ferroux, who held the post of foreman of the repairing shops, at the Mont Cenis Tunnel, and who therefore is presumedly acquainted with the defects of the Sommeiller drill, both in its original state and in its modified form as the Dubois-François. Ferroux's drill, like the last mentioned, is essentially the Sommeiller machine; but it possesses an arrangement for communicating a feed motion that is entirely novel. This arrangement obviates some at least of the defects of the automatic feed contrivances which have been adopted by other inventors; but it must be admitted that it has others from which those contrivances are free. The following description of this drill, which is illustrated in Fig. 197, is given by H. W. Pendred, C.E., the agent of the manufacturer in England.

"The 'Ferroux' borer consists of two cylinders, set end to end, and fitted with pistons, rods, and a frame in the machine for tunnels, while in the machine for mines and shaft sinking, &c., the cylinders are set side by side one above the other. The one is called the propelling cylinder, and the other the boring cylinder; the propeller feeds the borer up to its work. The compressed air is introduced into the machine through the coil, and enters the first cylinder, which is the propeller cylinder; in this is placed the piston, fixed on a tubular rod, the other end of which is securely fixed to the boring cylinder, in which reciprocates the piston and the boring rod. The compressed air entering at the coil produces three actions; first, it presses before it, in a continuous manner, the boring cylinder towards the rock to be perforated, and when the borer has pierced the rock to a depth equal to the 'pitch' of a tooth respectively, in a pair of racks fitted to the upper part, the boring rod, by means of a collar affixed on it, now raises a forked lever, which is provided with a pair of projections acting as 'pawls' on the racks fixed, and the borer is urged forward a distance equal to one notch of the rack. The boring cylinder is thus, as it were, consolidated with the action of the borer, but it is necessary that it should be also in a sense opposed to it; it is therefore provided with two small cylinders arranged horizontally; in each of these works a piston, so formed on its outer side as to act as a 'pawl,' which engages in the teeth of the rack formed on the inner face of each of the frame bars. The action of these 'pawls' is the reverse of those regulating the forward movement of the propeller, and they operate to prevent any greater degree of recoil on the part of the borer upon the propeller than the 'pitch' of a tooth in the racks, so that while such 'pitch' admits of an elastic cushion to soften the recoil action and prevent fracture, at the same time the 'play' is too

limited to vitiate the boring action. As the pistons are subject to the action of the compressed air, they are thus kept forced into the ratchet teeth, while their oblique leading faces prevent them obstructing the feed movement. The second action of the compressed air is to operate through the hollow rod, and supply power to actuate the boring piston in the cylinder. The air enters the valve box, and is alternately admitted before and behind the piston by the slide valve in the box. The third action of the compressed air is to actuate the air engine at the rear of the propeller cylinder. This engine is constituted of a cylinder within, which works a piston with a trunk rod, over which is a crank and shaft united to the piston by a connecting rod. The crank is a slotted one, having on the one side an eccentric to shift the slide valve for its own cylinder, and at the other side a socket sleeve into which the end of the long shaft is fixed. Beyond the bracket supporting this end of the shaft is a fly-wheel of exceedingly small diameter, so as to economise room for the headings, but wide enough to secure weight sufficient for steady working. The shaft is prolonged and supported in another bracket at the boring-bar end of the machine, and beyond it is an eccentric which actuates a reciprocating ratchet which engages in the ratchet wheel on the boring bar, giving it an intermitting rotary movement of one tooth 'pitch' at each blow dealt by the tool upon the rock. To withdraw the tool from its work it is only necessary to close the cock and open another, when the air which pushed the machine forwards escapes, and the compressed air passing through goes along a pipe to the front side of the piston and forces it back, which withdraws the tool and closes up the machine like a telescope. A socket serves to fix it to any supporting machine. It will be seen from the foregoing description and from the drawings that the propelling arrangement is perfectly separate and distinct from the boring machinery in its action, and that neither over nor under feeding can possibly take place. The above machine has been specially designed for tunnelling. It measures about 10 feet long when closed up, by 1 foot wide and 1 foot 2 inches deep. The stroke is $6\frac{1}{4}$ inches long, and the travel of the propelling piston is $2\frac{1}{2}$ feet; the weight of the machine without the carriage is about 2 tons. A smaller and lighter machine is made for ordinary mining and quarrying operations; in this the propelling cylinder is placed immediately beneath the borer. Very little experience has yet been had with the modified form of the machine."

The Burleigh Rock-Drill.—The Burleigh drill, which is an American invention, was the first machine of this kind that was adopted in the United States with undoubted success. Having stood the test of many years' experience, it is now largely employed in mining operations both on the American and on the European continents. Of the important works to which this machine has been applied, the excavation of the famous Hoosac Tunnel deserves special mention. The Burleigh drill, which is shown in Fig. 198, consists essentially of a cylinder A, and piston B, with its rods, and a valve gear *a*, *b*. Both the back and the forward piston rods pass through stuffing boxes in the cylinder; to the forward rod, the borer-bit is fixed by the means shown in the drawing; the back rod, which is made smaller in diameter than the forward rod, to give a larger piston area on that side, terminates in an annular protuberance. This protuberance on the piston rod is intended to strike alternately during its reciprocating motion the back and forward arms of the tappet lever *a*, to which the rod of the slide valve is attached. It will be evident that the rocking motion of the lever thus produced will communicate the requisite reciprocating motion to the valve, and by this means the desired action of the piston is ensured. To effect the rotary motion of the latter, the back piston rod is provided with a spiral feather, which works in a corresponding groove in a cylindrical piece fitting into the back portion of the cylinder. This cylindrical piece is provided on

the outside with teeth, thereby forming a kind of ratchet-wheel. A detent held up by a spring prevents the piece from turning in one direction, but allows it to revolve freely in the contrary direction. By this means, the piston is made to turn partially round during the back stroke; but, during the forward stroke, the piston turns the cylindrical piece before described, the motion of which in that direction is unrestrained by the detent. The earlier machines were provided with an automatic feed mechanism; but those now constructed are free from this complication of parts, which experience has shown can never in any drill be made to perform satisfactorily the work required of it.

The Ingersoll Rock-Drill.—The Ingersoll machine-drill is of American origin, and of recent introduction, and, as an improvement upon many pre-existing machines of a like character, it possesses numerous claims to notice. The designers of this drill have kept in view the conditions under which rock-perforating machinery has to work, and they have succeeded in fulfilling the requirements in an eminently satisfactory degree. The peculiarities of the Ingersoll drill will be rendered apparent by the following description of its design and construction, and the illustrations which accompany them.

In Figs. 201 to 203, E is the cylinder, M the piston, and L the piston rod. The valve gear is actuated by the piston through the medium of tappets, and consists of a slide-valve M′, two valve rods or spindles B, and two tappet levers H. The action of this valve gear and of the piston needs no description. The rotary motion of the tool is obtained by means of the spirally grooved bar S recessed into the back end of the piston. A cap screwed into the piston is provided with studs or feathers to run in the grooves of the bar. On the end of the latter, is a ratchet-wheel into the teeth of which a pawl is held by a spring. This pawl, as in the case of some other machines to be described, forces the piston to turn during the back stroke, but allows the spiral bar to rotate during the forward stroke. The forward motion of the cylinder, or feed motion, is produced automatically in the following manner. As the tool penetrates the rock, the piston approaches the forward end of the cylinder, and strikes against a tappet lever H′, which partially rotates the rod R, in the manner shown in Fig. 201. This rod turns, by means of pawls and ratchet-teeth, a nut upon the back end of the cylinder, through which nut passes the feed-screw P, as shown at V. The rotation of this nut upon the fixed feed-screw causes the cylinder to advance.

The design and the construction of this machine are simple and strong, and the moving parts are few in number. By the use of two tappet levers, rocking through a small arc, the violence of the shock caused by the blow delivered at each stroke of the piston is much lessened, and the wear of the parts proportionately diminished. Another contrivance for ensuring durability in the valve gear consists in making the spindles separate from the valves and from the tappet levers. There is ample clearance space at each end of the cylinder; but to lessen the destructive effect of a blow, should the piston strike the cover, an elastic cushion is provided.

The McKean Rock-Drill.—The characteristic features of the McKean rock-drill are shown in Figs. 199 and 200. Besides the anterior piston rod, to which the tool is attached, there is a posterior rod, which passes through the back end of the cylinder, and is prolonged through the valve-gear chamber situate behind the cylinder. Upon this prolongation of the rod is an enlargement, or a swelling, of an ovoid form, as shown in the drawing. During the reciprocating motion of the piston, this enlarged portion strikes alternately the arms *l* and *l′*, which hang upon opposite sides of the piston rod. By this means an oscillating motion is produced in the rod upon which the arms are

fixed, which motion is thereby communicated to the valve. The form and action of this valve will be understood from the drawing, Fig. 200. To give the requisite rotary motion to the tool, the enlarged portion of the piston rod is provided with spiral teeth, which gear into corresponding spiral teeth on a rotary cam-spindle, *o*. This cam-spindle is provided with a ratchet-wheel which is held by a pawl, so that the cam may turn only in one direction, and during the backward stroke of the piston. Such are the general features of the McKean drill as used in the St. Gothard tunnel. The machine is provided with ingenious mechanism for giving automatic feed; but for ordinary mining operations it is preferably constructed without this complication. A lighter form of this machine than the one illustrated is usually employed.

The Sachs Rock-Drill.—The machine drill, which is known by the name of its inventor, Carl Sachs, is widely employed in Germany. This drill has stood the test of many years' experience, and though it has been shown to be less durable in some of its moving parts than could be desired, it is still held in favour on the Continent. The machine, the design of which is particularly ingenious, is shown in Figs. 206 to 208. As the details of construction are therein clearly set forth, the action of the machine will be fully understood from a general description. It will be observed that the admission, cutting off, and exhausting of the motor fluid is effected by means of a slide valve of the ordinary character. This valve is worked by a bell-crank lever connected with the piston rod in a manner which is clearly shown in the drawing. Hence the motions of the valve and of the piston are mutually dependent. It will be observed that ample clearance speed is provided at each end of the cylinder. To give the requisite rotary motion to the tool, another cam of the rocking lever communicates a reciprocating motion to a rod shown partly in Figs. 206 and 207, and more fully in Fig. 208. Upon this rod, are fixed two ratchet-pawls, held up against the teeth of the ratchet-wheel upon a cylindrical piece through which the rod passes at the upper end of the steam cylinder. This piece is provided on the inside with a groove in which a feather or rib upon the rod slides. The action of the pawls in causing the wheel to revolve will be readily understood from an inspection of the drawing. The feed motion in the recent machines is communicated by hand in the usual manner by means of a screw and winch handle, or a wheel as described in the Dubois-François drill. The greater simplicity due to the abandonment of the automatic feed has rendered the Sachs a very efficient machine.

The Schram Rock-Drill.—Recently a new machine has been brought out as the invention of R. Schram, and introduced into many important works both in Sweden and in Germany. The following description of this machine, which is shown in Figs. 204 and 205, is given by Schram.

The drill consists of only four moving parts, namely, the working piston, to which the borer is fastened, the slide-valve, the slide-rod, and the small piston, by means of which the rotary motion of the main piston is obtained. All these parts are worked directly by the motor fluid.

It will be seen from the drawing, Fig. 204, that when the slide-valve and slide-rod *f* are in the position shown, steam passes through the port *b* into the cylinder *c*, and pressing on the under side of the piston *d*, causes it to make a stroke backwards. When the piston has passed the port *e*, steam enters through that port into the cylinder *g*, in the valve box, at the same time that the cylinder *k*, through the passage *i*, and the circular hollow in the piston *d*, communicate with the exhaust port *s*. Steam is then working with full pressure on the slide-rod *f* in the cylinder *g* at the moment when the cylinder *k* communicates with the exhaust; consequently the slide-rod, and with it the slide-valve, is forced towards the cylinder *k*, so that the passage *h* is open, and the port *b* communicates

with the exhaust port s. The steam now working in the cylinder $c' c''$ forces the piston d forwards, and, when passing the port communicating with the passage i, steam enters into the cylinder k at the same moment that the cylinder g, through the port communicating with the passage e, and the circular hollow in the piston d, communicate with the exhaust port s. The slide-rod is then forced back towards the cylinder g; the passage b is again opened, and the passage h, from the position of the slide-valve, is placed in communication with the outlet. The piston d then makes a backward stroke, and the action is repeated so long as the supply of steam is maintained.

The slide-rod f is made in the form of two spindle valves; by this method of construction it remains in its position without recoil until the piston d has made the greater part of its stroke. In consequence of the bevelled form of the faces, at the end of the travel, there is always a cushion of steam between the valve and the box, and the valve remains perfectly closed until sufficient steam is released from the cylinder to reverse the piston.

When steam is let into the cylinder $c' c''$, it lifts the small piston l; the piston d is then forced outwards without touching any other part, and the whole power is effectually utilized. On the upper part of the small piston l, which is contained in the small cylinder n, a constant pressure is maintained through the passage m. As before remarked, when the piston d makes its backward stroke, the cylinder $c' c''$ communicates with the exhaust; consequently the small piston l, through the pressure in the small cylinder n, is pressed against the piston rod o, so that the teeth of the small piston l catch the grooves in the ratchet end of the piston rod o, and from the spiral form of the latter, the piston is caused to rotate.

Like most other mining engineers experienced in rock boring, Mr. Schram considers an automatic feed motion impracticable, owing to the want of uniformity in the texture and composition of rock; and he, therefore, has preferred to leave the feed motion to the workman, who must be constantly in attendance upon the machine.

The merits claimed for this machine are:—That the piston is perfectly free; that the full pressure of the steam is kept on during the whole of the stroke; that the loss from friction is very small; that no part other than the piston is exposed to shocks; that the moving parts are few, and readily accessible; and that the construction of the whole machine is simple and favourable to strength.

The Darlington Rock-Drill.—The machine which in England has stood the test of experience most satisfactorily, and which, consequently, is surely working itself into general favour in this country, and also in some of the important mining districts of the Continent, is the invention of John Darlington, and is known as the Darlington drill. This drill is remarkable as the attainment of the highest degree of simplicity of parts possible in a machine. The valve gear of a machine drill is especially liable to derangement. It must necessarily consist of several parts, and these parts must as necessarily be of a somewhat fragile character. Besides this, when actuated by the piston through the intervention of tappets, the violence of the blow delivered at each stroke is such as to rapidly destroy the parts. In some of the machines already described, the force of these blows and their destructive tendency have been reduced to a minimum; but when every means of remedying the evil has been employed, there remains a large amount of inevitable wear and tear, and a liability to failure from fracture or displacement exists in a greater or less degree. Moreover, as these effects are greatly intensified by increasing the velocity of the piston, it becomes at least undesirable to use a high piston speed. To remedy these defects, which are inherent in the system, Darlington proposed

to remove altogether the necessity for a valve gear by radically changing the mode of admitting the motor fluid to the cylinder. This proposal he has realized in the machine which is illustrated on Plate XXXIII.

The Darlington rock-drill consists essentially of only two parts: the cylinder A, Fig. 212, with its cover; and the piston B, with its rod. The cover, when bolted on, forms a part of the cylinder; the piston rod is cast solid with the piston, and is made sufficiently large at its outer end to receive the tool. These two parts constitute an engine, and with less than one fixed and one moving part, it is obviously impossible to develop power in a machine by the action of an elastic fluid. The piston itself is made to do the work of a valve in the following manner: The annular space affording the area for pressure on the fore part of the piston gives a much smaller extent of surface than that afforded by the diameter of the cylinder, as shown in Fig. 212; and it is obvious that, by increasing or diminishing the diameter of the piston rod, the area for pressure on the one side of the piston may be made to bear any desired proportion to that on the other side. The inlet aperture or port C being in constant communication with the interior of the cylinder, the pressure of the fluid is always acting upon the front of the piston; consequently, when there is no pressure upon the other side, the piston will be forced backward in the cylinder. During this backward motion the piston first covers the exhaust port D, and then uncovers the equilibrium port E, by means of which communication is established between the front and back ends of the cylinder, and consequently the fluid made to act upon both sides of the piston. The area of the back face of the piston being greater than that of the front face by the extent occupied by the piston rod, the pressure upon the former first acts to arrest the backward motion of the piston, which by its considerable weight and high velocity has acquired a large momentum, and then to produce a forward motion, the propelling force being dependent for its amount upon the difference of area on the two sides of the piston. As the piston passes down, it cuts off the steam from the back part of the cylinder and opens the exhaust. The length or thickness of the piston is such that the exhaust port D is never open to its front side; but in the forward stroke it is open almost immediately after the equilibrium port is closed, and nearly at the time of striking the blow. It will be observed that the quantity of fluid expended is only that which passes over to the back face of the piston, since that which is used to effect the return stroke is not discharged.

The means employed to give a rotary motion to the tool are deserving of special attention, as being simple in design, effective in action, and well situate within the cylinder. These means consist of a spiral or rifled bar H, having three grooves, and being fitted at its head with a ratchet-wheel G, recessed into the cover of the cylinder. Two detents J J, Fig. 214, also recessed into the cover, are made to fall into the teeth of the ratchet-wheel by spiral springs. These springs may, in case of breakage, be immediately renewed without removing the cover. It will be observed that this arrangement of the wheel and the detents allows the spiral bar H to turn freely in one direction, while it prevents it from turning in the contrary direction. The spiral bar drops into a long recess in the piston, which is fitted with a steel nut, made to accurately fit the grooves of the spiral. Hence the piston during its instroke is forced to turn upon the bar; but during its outstroke it turns the bar, the latter being free to move in the direction in which the straight outstroke of the piston tends to rotate it. Thus the piston, and with it the tool, assumes a new position after each stroke.

The mode of fixing the cutting tool to the piston rod is a matter deserving some attention. As the tool has to be changed more than once during the progress of a bore-hole, it is important that

the change should be accomplished in as short a time as possible; and as the vibration of the machine and the strain upon the tool are necessarily great, it is equally important that the tool be firmly held. It is also desirable that the mode of fixing the tool shall not require a shoulder upon the latter, a slot in it, or any peculiarity of form difficult to be made in the smithy. If the foregoing machines be compared in this respect, it will be found that the Darlington fulfils the requirements of expedition in fixing, firmness of retention, and simplicity of form most satisfactorily. The means and the method are the following: The outer end of the rod or holder is first flattened to afford a seat for the nut, as shown in Figs. 212 and 214. The slot is then cut and fitted tightly with a piece of steel K, forged of the required shape for the clamp, and the holder is afterwards bored to receive the tool while the clamp is in place. This clamp K is then taken out, its fitting eased a little, and its end screwed and fitted with a nut. When returned to its place in the holder, the clamp, in consequence of the easing, can be easily drawn tight against the tool, by which means it is firmly held in position. The shank of the tool is turned to fit the hole easily, and the end of it is made hemispherical to fit the bottom of the hole, upon which the force of the reaction of the blow is received.

It would seem impossible to attain a higher degree of simplicity of form, or to construct a machine with fewer parts. The absence of a valve or striking gear of any kind ensures the utmost attainable degree of durability, and allows a high piston speed to be adopted without risk of injury. As the piston controls its own motion, there is no liability to strike against the cylinder cover. The stroke may be varied in length from half an inch to 4 inches, and as the machine will work effectively with a pressure of 10 lbs. to the inch, holes may be started with the greatest ease. With a pressure of 40 lbs., the machine makes 1000 blows a minute, a speed that may be attained without causing undue strains or vibration. This alone constitutes a very great advantage. It must, indeed, be conceded that an unprejudiced consideration of the merits of this drill shows it to be admirably adapted to the work required of it.

The Beaumont Rock-Drill.—A new machine-drill has lately been brought out by the "Diamond Rock-Boring Company," as the invention of their manager, Major Beaumont, R.E. This machine, so far as it has yet been applied, is said to have given very satisfactory results. Its design, construction, and action will be understood from the following description and the drawings, Figs. 209 to 211.

In these drawings, A is the drill cylinder, with piston B and piston rod C to which the drill is attached. The valve casing D has a central closed chamber D^1 and two outer chambers D^2, D^3, which at their outer ends are open to the atmosphere. The chamber D^1 contains a double piston E, and communicates at each end through ports F, F^1, with the drill cylinder. The two end chambers D^2, D^3, contain two piston valves G, G^1, which are connected to the piston E by stems as shown, so that the reciprocating motion of the piston E is imparted to the valves. The chambers D^2, D^3, have ports H, H^1, by which they communicate with the ends of the cylinder A; and they have other ports at their inner ends communicating with the fluid pressure supply pipe I through the passage I^1.

Assuming the drill piston to be at the end of its forward stroke, and the valves G, G^1, and piston E to be in the position shown at Fig. 3, it will be seen that the valve G is in position to admit fluid pressure through the port H to the front end of the piston B, while the valve G^1 has uncovered the port H^1 so as to put the back end of the piston B in communication with the external atmosphere. At the same time the port F of the chamber D^1 is in communication with an annular

cavity B^1 in the piston (which is permanently open to the exhaust through the opening A^1 in the cylinder A) and the port F^1 is open to the back end of the cylinder.

The drill piston B with the drill will now make its back stroke, and in doing so will uncover the port F so as to admit the fluid pressure from the cylinder A to the front end of the piston E, while at the same time the port F^1 will be put in communication with the cavity B^1, thus causing the back end of the piston E to communicate with the exhaust; by this means (the pressures on the valves G, G^1, being balanced) the piston E will be made to move to the right hand, thus causing the valve G to open the port H to the atmosphere, and the valve G^1 to open the port H^1 to the fluid pressure; the piston B will then perform its forward stroke, and the piston E and valves G, G^1, will move back into the position shown on the drawing. Caoutchouc buffers K are provided at the end of the chamber D^1 for the piston E to strike against.

The drill piston B is made with a square or polygonal cavity B^2, into which fits the head L^1 of a cylindrical rod L, which works air-tight in the tube M fixed to the cylinder cover. This rod has an extension L^2 of square section passing through a square hole in the boss of a pinion N, on which is fixed a ratchet-wheel N^1. Beyond this pinion, the rod is formed with a helical twist, and passes through a square hole at the end of a tubular spindle O, on which a ratchet-wheel O^1 is fixed, and which is carried by a bracket P from the cylinder A. The ratchet-wheels N^1, O^1, are prevented by pawls N^2, O^2, from rotating in one direction. As the drill piston B performs its back stroke it pushes the rod L outwards, and the twisted or helical end of L^2 being thus caused to slide through the tubular spindle O, which is prevented from turning by the pawl O^2, the rod L will be turned somewhat on its axis, and this will consequently effect a partial rotation of the drill piston and drill by means of the head L^1 fitting in the recess B^2. At the same time the rod L in turning will also cause the pinion N^1 to turn. This pinion is in gear with a pinion Q on a screwed sleeve R held in a bracket S on the side of the drill cylinder A, through which sleeve R passes a screw spindle T held in the brackets U^1 on the framing of the rock drill.

Thus by the rotation of the pinion N^1 the sleeve R is turned on this screw spindle, whereby the drill cylinder is made to advance somewhat at every back stroke of the drill piston. During the forward stroke of the drill piston, the rod L being moved with it by the pressure acting on the shoulder of L^1, the rod L is drawn back through the tubular spindle O, whereby the spindle O and ratchet-wheel O^1 are made to turn, while the rod L, and consequently the piston and drill, are prevented from turning back by the ratchet-wheel N^1 held by its pawl N^2.

The screw spindle is held with sufficient friction in its bearings U^1, U^1, to prevent its turning while the sleeve R is rotated upon it, but it can be turned by a winch handle fitted on its square end in order to draw the drill cylinder back after a hole has been drilled.

ROCK-DRILL SUPPORTS.—A machine rock-drill may satisfy every requirement, and yet by reason of the defective character of the support to which it is attached, it may be unsuitable to the work required of it. Hence it becomes desirable to carefully study the design and construction of a drill support, and to consider the requirements which it is needful to fulfil. Assuming the necessity for a high degree of strength and rigidity in the support, a primary condition is that it shall allow the machine to be readily adjusted to any angle, so that the holes may be bored in the direction and with the inclination required. When this requirement is not fulfilled, the machine is placed, in this respect, at a great disadvantage with hand labour. If a machine drill is not capable of boring in any position, and in any direction, hand-labour will have to be employed in conjunction with it, and such incompleteness in the work of a machine constitutes a serious objection to its adoption.

Besides allowing of the desired adjustment of the machine, the support must be itself adjustable to uneven ground. The bottom of a shaft which is being sunk, or the sides, roof, and floor of a heading which is being driven, present great irregularities of surface, and as the support must of necessity, in most cases, be fixed to these, it is obvious that its design and construction must be such as will allow of its ready adjustment to these irregularities. The means by which the adjustment is effected should be few and simple, for simplicity of parts is important in the support as well as in the machine, and for the same reasons. A large proportion of the time during which a machine drill is in use is occupied in shifting it from one position or one situation to another; this time reduces in a proportionate degree the superiority of machine over hand labour in respect of rapidity of execution, and it is therefore evidently desirable that it should be shortened as far as possible. Hence the necessity for the employment of means of adjustment which shall be few in number, rapid in action, and of easy management.

For reasons similar to the foregoing, the drill support must be of small dimensions, and sufficiently light to allow of its being easily portable. The limited space in which rock drills are used renders this condition, as in the case of the machine itself, a very important one. It must be borne in mind that after every blast the dislodged rock has to be removed, and rapidity of execution requires that the operations of removal should be carried on without hindrance. A drill support that occupies a large proportion of the free space in a shaft or a heading is thus a cause of inconvenience and a source of serious delay. Moreover, as it has to be continually removed from one situation to another, it should be of sufficiently light weight to allow of its being lifted and carried without difficulty. In underground workings, manual power is generally the only power available, and therefore it is desirable that both the machine and its support should be of such weight that each may be lifted by one man. Of course, when any endeavour is made to reduce the weight of the support, the necessity for great strength and rigidity must be kept in view.

In spacious headings, such as are driven in railway tunnel work, supports of a special kind may be used. In these situations, the conditions of work are different from those which exist in mines. The space is less limited, the heading is commenced at surface, and the floor laid with a tramway and sidings. In such a case, the support may consist of a massive structure mounted upon wheels to run upon the rails. This support will carry several machines, and to remove it out of the way when occasion requires, it will be run back on to a siding. But for ordinary mining purposes, such a support is unsuitable.

The support adopted at the Mont Cenis tunnel was an iron carriage constructed to run upon rails, and having a height of about 5 feet 9 inches above the rails, a breadth of 2 feet 8 inches, and a length of about 33 feet. It was mounted upon two pairs of cast-iron wheels 2 feet in diameter. The fore pair was made to gear into a pinion worked by a hand-wheel, by means of which two men were able to run the carriage backwards and forwards upon the rails. This heavy carriage, the design of which is shown in Figs. 218 to 220, was composed of two horizontal frames, connected by vertical flat iron bars. The mode of construction will be understood from the drawings.

The support thus constituted is divided into three portions: that which is beyond the fore wheels is intended to carry the boring machines, of which there are ten, four inside, and three on each side of the carriage; the portion comprised between the fore and the hinder wheels forms a receptacle for reserve machines, drills, and tools; and the portion behind the hinder wheels constitutes a little workshop furnished with bench and vice, where urgent repairs may be effected. The carriage is fixed in position at the face of the heading by lifting the fore pair of wheels from

the rails by means of two screws made to bear upon a wooden sleeper laid on the ground for that purpose. This mode of fixing proved sufficient at Mont Cenis, the weight of the carriage being very great. The machines are carried upon a system of supports capable of being moved up or down upon vertical screws fixed upon each side of the carriage. This arrangement, which allowed the machine to be raised or depressed at pleasure, and directed at any required angle, is shown in the drawing referred to; upon the carriage, there are a reservoir of air and a reservoir of water in communication with it. The water being thus under pressure can be easily forced into the bore-holes.

This drill carriage, constructed of smaller dimensions to reduce its weight, and slightly modified in its details, is still commonly used with the Dubois-François machines.

The simplest kind of support is the "stretcher bar." This consists essentially of a bar so constructed that it may be lengthened or shortened at pleasure by means of a screw. It is fixed in position by screwing the ends into firm contact with the sides, or with the roof and the floor of a heading, or with the side of a shaft. The machine is fixed to this bar by means of a clamp, which, when loosened, slides along the bar and allows the drill to be placed in the required position, and to be directed at the required angle. The stretcher bar with a back strut, illustrated in Figs. 221 and 223 is that which is used with the Darlington drill; in it rigidity and lightness are combined in the highest possible degree by adopting the hollow section. The mode of setting the stretcher bar in a shaft is shown in Fig. 224; in this case two drills are worked upon the same bar. A similar mode of fixing the bar is adopted in a heading; but the usually smaller dimensions of the latter excavations render it inconvenient to work two drills upon one bar.

For shaft sinking, however, a support of the kind shown in Figs. 225 to 227 is preferable. It consists essentially of two stretcher bars hinged upon a central leg. This leg is set in the middle of the excavation, and the arms, which constitute the stretcher bars, are screwed up against the sides of the shaft. To steady the bars laterally, two struts, which are also hinged to the central leg, are used, as shown in the drawings. These struts, like the arms, are capable of being lengthened or shortened at pleasure. The machines are fixed upon the arms in the usual manner by means of clamps. A chain is attached to the central leg for the purpose of raising and lowering the support in the shaft. To this chain is set a pulley-block, through which lines run to the extremities of the arms, as shown in the drawings. When the holes have been bored, the arms upon which the drills are fixed are loosened from the sides of the shaft, and drawn up into nearly the vertical position by means of the lines and pulley-block referred to, and the whole is raised in the shaft by means of the chain attached to the central leg. When the block has been fixed, the chain is again lowered, and the arms dropped into position.

In headings, the simple stretcher bar is frequently used. But a more satisfactory support is afforded by a bar suitably mounted upon a carriage designed to run upon rails. The carriage consists simply of a trolley, to the fore part of which the bar is fixed by some kind of hinge joint. It is obvious that the details of the construction of this support may be varied considerably, and numerous designs have been introduced and adopted.

Schram's carriage support, or gadding car, for driving galleries and headings, is shown in Figs. 228 and 229. This support consists of two vertical stretchers, on which the rock-boring machines are arranged, and from which they may be directed at any desired angle. Each carriage will accommodate from two to four machines.

When the carriage is at the working face, the stretchers, which during the removal have been

lifted by means of the nuts *a*, are lowered on to a piece of hard wood *b*; the stretchers are then fastened by the screws *c*, a piece of wood *d* having first been fixed above their crowns. When the main air-pipe *e* is connected with the carriage through the nut *f*, the machine may be levelled to any desired height by means of the nuts *a*, and when fixed by the universal joints *g*, the boring may at once commence.

When all the holes are bored, and the support must be removed, the stretchers are unfastened by means of the screws *c*, and lifted by the nuts *a*. Where the heading is not high enough to allow the stretchers to remain upright while the support is removed, it is only necessary to remove the screws *h*, and the stretchers can be laid back on the carriage with the screws *i* as their axis.

It will be seen from the drawing that this support is easily fixed and removed, and that it allows a free space for the boring machines and the workmen, while the machines may be directed at any desired angle. There is no doubt a great advantage in working with two separate supports, for when the debris from one side has been removed, the boring can be recommenced with one support while the other side is being cleared, and thus a considerable saving of time may be effected.

A support of similar design has been introduced by Darlington, and adapted for use with his drill. In this support only one stretcher bar is used, which is provided with revolving arms for the attachment of the machines. This arrangement gives undoubtedly greater facilities for working the drill, and leaves the heading less encumbered.

For open work, as in quarrying, where the stretcher bar cannot be used, the tripod stand is adopted. A necessary requirement of the tripod is that its construction shall allow the machine to be directed at the desired angle. On Plate XXXVIII. two forms of the tripod stand with the machine attached are shown. To steady the machine, heavy weights are sometimes hung upon the legs of the tripod.

Air-compressing Machines.—The employment of compressed air as a means of transmitting force may be regarded as one of the most remarkable mechanical achievements of the present times. No doubt as a means of utilizing distant and yet unavailable sources of force, the importance of this medium can hardly be over-estimated, for it is abundantly clear that it possesses qualities which may render it productive of immense benefits in that direction. But it is in its application to mining purposes, which afford the most favourable opportunities for its employment, that it is destined to undergo its complete development and to attain its highest degree of usefulness. To the altogether exceptional nature of the situations in which mining operations are carried on, the peculiar character of these operations themselves, and the otherwise difficult conditions under which they have to be performed, the qualities of compressed air render it particularly suitable. Its easy conveyance to any point of the underground workings, and its ready application at any point; the improvement which it produces in the ventilative currents; the complete absence of heat in the reservoir and conducting pipes, a condition which tends greatly to their preservation; these and numerous other advantages, when contrasted with the defects of steam under like conditions, give to compressed air a value which the mining engineer will fully appreciate. In applying a motor fluid underground, it is rather a question of distributing small forces over a large number of points, than of concentrating a large force at one or two points. This is particularly the case when it becomes necessary to employ hauling engines, coal-cutting machines, and portable rock-drills, the positions of which are daily changing. To satisfy conditions such as these, compressed air is alone admissible. Great, however, as the merits of compressed air as a medium for transmitting force are, it possesses defects

of an important character. These defects lie chiefly in its inherent and essential qualities as a gas, whereby a loss of the force to be transmitted is occasioned. The amount of the loss due to this source is necessarily considerable; but when due precautions are not taken to keep it near its minimum limits, it may assume very grave proportions. There can be no reasonable doubt that the best machines and appliances now in use for the compression of air are excessively wasteful of the motive force.

The most important source of loss of work in compressing air is the accumulation of heat. The means of remedying the evil lies in the application of a suitable medium of abstraction. Hitherto water has shown itself to be the most effective and convenient body for such a purpose, and numerous modes of applying it have been devised in order to obtain the best possible results. To favour the action of the water, the velocity of the piston should be kept low. This would appear to be a necessary condition of efficiency.

Another source of loss of work, the consequences of which increase in importance with the degree of compression, is the clearance space at the end of the cylinder. These consequences will, on reflection, become sufficiently apparent. Suppose a cylinder in which the compression is carried to six atmospheres. When the piston arrives at the end of its stroke the clearance space contains air compressed into one-sixth of its volume at atmospheric pressure; and it is obvious that when the piston recedes, this air must expand into six times that volume, that is, into its volume at atmospheric pressure, before any air from the surrounding atmosphere can enter the cylinder; or, in other words, before the suction valve can open. Thus a volume of air is lost at each stroke equal, at atmospheric pressure, to that assumed by the compressed air in the clearance space when, by expansion, it has dropped to the same pressure. To remove altogether the necessity for a clearance space, columns or cushions of water have been employed, in a manner which will be described hereafter. These fulfil the purpose required very satisfactorily; but it must be borne in mind that they are themselves a source of loss of work, by the inertia which they oppose to the motive force. It should be remarked that the contents of the clearance space includes the air in the receiver behind the valve, which air returns into the cylinder as the valve closes. This is called the slip of the valve, that is, the quantity of air which the valve as it returns to its seat allows to slip back into the cylinder. When the lift of the valve is great, this quantity may be considerable; and when the lift is slight, the resistance from friction, due to the contracted passages, may also be considerable.

Leakage of the valves and pistons and the friction of the moving parts constitute sources of loss of greater or less importance according to the degree of perfection attained in the construction of the machine, and the condition in which it is maintained. As these sources of loss are greatly dependent for their existence upon design, workmanship, and supervision, they are capable of being reduced to narrow limits. It is, however, needful to remark here that the loss of work due to the friction of the air in the valve-ways, and to the influence of the contracted vein, is by no means insignificant.

There is yet another source of loss of motive force, the influence of which is very great, and which increases with the degree of compression. This source of loss exercises an important bearing upon the question of economy relatively to this mode of transmitting force, and is, therefore, deserving of careful consideration. As the air has to be compressed by the application of force, it is clear that the fraction of that force which remains after the important deductions have been made for the losses already described, cannot be fully recovered without working the air expansively down to the pressure of the atmosphere. As this is in all cases impracticable, there must be always a loss

of work, the value of which may be determined from the degree of expansion adopted. In the case of machine rock-drills, which work without expansion altogether, the loss is necessarily very great, and, when high pressures are used, may become enormous.

Compressed air has to be conveyed in pipes and tubes from the reservoir into which it has been forced, to the machines in position at the various points where operations are being carried on, through distances in many cases considerable. During this transmission, a loss of work is occasioned by the friction of the air in the pipes. Numerous and exhaustive experiments have been made to determine accurately the value of the loss thus occasioned. From the results of these experiments the following three conclusions have been deduced, namely; 1, that the resistance is directly as the length of the pipe; 2, that it is directly as the square of the volocity of flow; and 3, that it is inversely as the diameter of the pipe. Upon these results and conclusions formulæ have been established whereby the value of the loss of force may be ascertained with ease and accuracy. These formulæ show that for pipes of the diameters usually employed for this purpose, and for distances not exceeding one mile, the loss of motive force due to the friction of the air in the pipe is insignificant when the velocity does not exceed 4 feet a second. And it can be shown that even this loss is notably diminished, and in some cases entirely annulled, by the increased head due to the depth of the shaft, when the compressed air is employed in mines. The influence of this head may often be taken advantage of to diminish slightly the diameter of the pipes, and thereby to effect a considerable economy of cost. This source of loss of motive force is of small moment when compressed air is applied to ordinary mining operations, so long as the velocity is kept below the limit already mentioned.

It becomes apparent from a consideration of the foregoing facts that compressed air as a medium of transmission is, under the most favourable conditions, exceedingly wasteful of the motive force, and that the waste may become enormous if means are not employed to keep it near its minimum limits. The application of such means involves conditions which can be satisfied only when the machinery employed for the compression is designed to form a portion of the permanent plant of a mine. Even with machinery of this character as at present constructed, not more than 30 per cent. of the motive force remains to be utilized when the necessary deductions for loss have been made; and calculations for practical purposes ought, therefore, to be based upon this, or a smaller proportion. It will be found instructive to compare the results of carefully conducted experiments with a compressor constructed on the principle adopted by Sommeiller at the Mont Cenis tunnel, and applied, with improvements of detail, to supply the rock-boring machines employed at the Sarrebruck mines, which results have been tabulated by the engineer, M. Pernolet, as follows:

No. of the Experiment.	Revolutions a Minute.		No. of Revolutions in the Engine required to give in the Receivers an Excess of Pressure of			Useful Effect of the Compressors at		
	Engine.	Compressor.	One Atmosphere.	Two Atmospheres.	Three Atmospheres.	One Atmosphere.	Two Atmospheres.	Three Atmospheres.
1	14·83	5·51	108	230	359	0·94	0·88	0·85
2	21·26	7·90	107	229	356	0·95	0·885	0·855
3	29·76	11·06	109	231	358	0·93	0·88	0·85
4	35·20	13·09	107	226	352	0·95	0·90	0·865
5	44·62	16·59	108	234	367	0·94	0·87	0·83
6	48·50	18·03	109	238	380	0·93	0·85	0·80

The compression cylinder was in this instance 0·393 mètre = 15·47 inches in diameter, and the length of the stroke was 1·255 mètre = $49\frac{1}{2}$ inches. The ratio of the gear being 29 : 78, one revolution in the compressor corresponded to 2·69 in the engine. During the first four experiments there was no sensible elevation of temperature in the valve-box; but in the fifth an increase of temperature became apparent; and in the sixth this increase was very marked. It will be remarked that up to thirty-five revolutions of the engine, corresponding to 13·09 of the compressor, = 21·5 inches a second, the useful effect remains independent of the velocity; but that beyond this it diminishes notably as the velocity increases. In consequence of the results obtained from these experiments, the maximum velocity of the compressors was fixed at eighteen revolutions a minute, = $29\frac{1}{2}$ inches a second. The ordinary speed, however, was hardly more than half this.

In nearly all recent instances in which compressed air has been applied on an important scale, preference has been given to water-column compressors, in which the piston acts upon the air through the medium of a mass of water that rises at each stroke to the delivery valve, and thereby reduces the clearance space to zero, while the air is kept saturated with water during the compression. But such machines, in which there is always a considerable mass of water in motion, must necessarily be driven at a low speed, and hence, when large volumes of compressed air are required, recourse must be had to increased dimensions. This necessity involves a large outlay, and this outlay often constitutes an insuperable difficulty in the way of adopting rock-boring machinery. Many attempts have been made to remove this defect by omitting the column of water, and thereby allowing the piston to act directly upon the air to be compressed. Few of these attempts have, however, proved sufficiently successful to justify the adoption of the system. In most of the compressors so designed the air becomes greatly heated, notwithstanding the precautions taken to prevent such a result. There are, however, some notable instances in which success has been achieved in an eminent degree, and these instances are deserving of special and careful consideration by reason of the important results to which they lead. Of these, the compressor in use at the St. Gothard tunnel, and known, from the name of its inventor, as Colladon's machine, is the most noteworthy.

Sommeiller's Air-Compressor.—The form of compressors adopted by Sommeiller at the Mont Cenis tunnel remains the most efficient in use. The special advantages claimed for these machines are: 1, that they occasion no loss by clearance space; 2, that they compress the air to four atmospheres without sensibly raising its temperature; and 3, that they occupy but little space, and that, moreover, their compactness does not render their parts less accessible for repairs.

The construction and arrangement of the compressors illustrated, which are very simple in their action, will be seen by referring to Figs. 234 and 235. They consist of a horizontal cast-iron cylinder 17·7 inches in diameter, and 39·37 inches long, firmly fixed to a horizontal bed-plate, in which moves the compression piston, which is packed with a leather packing. At each end of this principal cylinder, and communicating freely with it, is another cylinder or vertical column, which, like the first, is partially filled with water. Two gun-metal clack-valves, faced with leather, opening from the outside inwards, and having each a surface of about 15 square inches, serve for the admission of the air; whilst a horizontal valve, placed at the summit of the vertical columns, permits the escape of the compressed air into the conducting pipes and the reservoir. The two vertical columns are identical in their construction, and form, with the horizontal cylinder, a double-acting air-compressing engine. The piston rod is cased with gun-metal, in order to prevent the rapid oxidation of the iron which would take place if it were in contact with the water charged with

air at a high pressure. The glands of the stuffing boxes are for the same reason made of gun-metal.

The volume of air given at each stroke of the piston is in practice 4·9 cubic feet; theoretically, this quantity should be 5·6 cubic feet, thus showing a loss of from 10 to 12 per cent. This apparatus, therefore, theoretically perfect as it is in all parts of its construction, is, practically, far from being so; the loss, however, appears to be due more to the presence of a certain quantity of air, which is held suspended in the water, and which at the moment of opening the suction valves expands, and thus prevents the inrush of the air, than to any loss occasioned by leakage or loss of stroke.

At each stroke of the piston a certain quantity of water is carried over with the air into the reservoir, Fig. 249, which would finally become full if no precautions were taken to prevent it. In order to avoid leaving the conduct of this operation to the care and watchfulness of the workmen, a very simple apparatus is employed. At the bottom of the air-reservoir, the capacity of which is 882·5 cubic feet, is fixed a small copper pipe, which can be closed at pleasure by means of a stop-cock. During the working of the compressors, this cock is slightly opened, so as to allow the water, which is carried into the reservoir with the compressed air, to escape by the pipe into a cistern which receives its water from a common well-pump. The level of the water in this cistern is such that the overflow runs of itself into the tank of the compressors, where its flow is regulated by cocks provided for that purpose. By these means, if there be only a small quantity of water at disposal, it may be made to serve over and over again indefinitely. The only precaution necessary to be taken is, not to open the cock, before there is some water in the reservoir, and so to arrange the discharge pipe that the compressed air may not escape with the water.

The water in the compressor cylinder, being thus constantly renewed, prevents the heating of the air, which otherwise would attain to a very high temperature, a result that would be detrimental to the action and the duty of the machine. When working under ordinary conditions, the temperature of the air-pipes remains sensibly the same as that of the surrounding air, even when the latter is as low as 68° Fahr.

As a precaution against the occurrence of accidents, which might happen to the compressors if the pressure became excessive, a safety valve is placed upon the pipe through which the air passes to the reservoir, and a counterweight on this valve is so regulated as to allow the valve to rise under a pressure of $4\frac{1}{2}$ atmospheres. This safety valve is altogether independent of that situate upon the reservoir itself.

Colladon's Air-Compressor.—Colladon's air-compressor, the general arrangement of which is shown on Plates XL. to XLIII., consists of a horizontal cylinder having a hollow piston the rod of which, also hollow, passes through both ends of the cylinder, the suction and discharge valves being placed in the cylinder covers. The peculiarity in the construction of this compressor, which has been adopted at the St. Gothard tunnel, consists in the means adopted for cooling those parts of the apparatus which are brought into contact with the compressed air. These means, which are very ingeniously arranged, are: a circulation of water round the cylinder and through the cylinder covers, piston, and piston rod; and an injection of water, in the form of spray, into the two ends of the cylinder. The circulation of the water in the cylinder covers and round the cylinder is effected by means of a small pump placed at the side of the cylinder, the plunger of which takes its motion from the cross-head of

the compressor piston rod. This pump forces the water, through copper tubes having an internal diameter of about $\frac{3}{4}$ inch, into the spaces *a a*, Fig. 238, cast in the thickness of the cylinder covers, and into the annular space *b b* formed between the cylinder and its outer casing or jacket; the water passes off through similar tubes situate in the bottom of the cylinder jacket. By this means, a constant and regular flow is maintained. The circulation of the water in the piston and the piston rod is carried on by the following arrangement. The piston rod, which is of steel, is bored throughout its whole length to a diameter large enough to receive a copper tube *c c* and leave a small annular space around it. This tube is nearly equal in length to the piston rod, and is fastened to it at its back end by means of a brass screwed plug, into which penetrates, with easy friction, through the glands of the stuffing box, a pipe *f f*, which is firmly fixed to the cylinder by means of an iron strap *g g*. The water, driven by the pump already mentioned, passes through this pipe into the tube *c c*. Having reached the forward end of this tube, it returns, through the annular space left between it and the piston rod, as far as the diaphragm *e*, which consists of a brass ring fastened to the piston rod in the same line as the piston. This diaphragm obliges the water to pass into the piston, and to cool successively its two faces, as shown in the section, Fig. 238. The water afterwards escapes through the indiarubber pipe *i*, which is fixed to the back end of the piston rod. The water is injected into each end of the cylinder by means of two small pipes, Figs. 239 and 241, fixed in the upper part of the cylinder, their ends being closed by a metal disc *l*, and pierced by two inclined holes opening opposite each other, and having a diameter of about one-fiftieth of an inch. The water being forced, under considerable pressure, through these holes by means of the feed-pump, one jet strikes against the other, and is thereby divided into very fine spray. The quantity of water to be introduced by this means is so regulated by experiment as to keep the air completely saturated. Under these conditions, even when the circulation in the interior of the piston is cut off, the temperature of the apparatus will not rise above 95° Fahr. All the parts, indeed, remain cool, with a velocity of sixty-five revolutions per minute, and with the air compressed to six atmospheres. In each end of the cylinder there are two suction valves and one discharge valve, formed of very thin plates of steel with bronze seatings, the valves being kept in contact with the seating by means of spiral springs coiled round the valve stems, Fig. 240. The dimensions of these valves are as follows: Suction valves, internal diameter of seating, $4\frac{1}{4}$ inches; external diameter of valve, 5 inches. Discharge valves, internal diameter of seating, $3\frac{5}{8}$ inches; external diameter of valve $4\frac{1}{3}$ inches.

At the Airolo end of the St. Gothard tunnel twelve of these compressors have been erected, in groups of three on one side of a common driving shaft, which is set in motion by four distinct turbines by means of powerful bevelled gearing. The coupling boxes or clutches employed allow the isolation of each of these four groups with its motor, while by another mechanical arrangement, which disconnects the bevelled gearing, either of the motors may be stopped, the corresponding group of compressors receiving motion from the common driving shaft. These arrangements greatly facilitate the carrying out of repairs, as they allow of any one group of compressors being stopped without interfering with the working of any other part of the machinery; for even if it be necessary at the same time to repair one of the turbines and a compressor, belonging to different groups, the remaining nine compressors can be driven, as already shown, by means of the common driving shaft. In each group, the three compressors, *o*, *o'*, *o''*, Fig. 237, are fixed side by side upon one bed-plate, and connected directly to the three-throw crank-shaft P; this shaft is

connected by means of the couplings Q Q′ to the driving shafts R R′, thus producing a continuity between the shafts of each group. On these driving shafts are keyed massive bevelled toothed-wheels *s*, which are driven by horizontal turbines T, Fig. 236.

The dimensions of the compressors at Airolo are:

Diameter of piston	18·1	inches.
Stroke of piston	17·7	„
The theoretical volume generated by the compressor at each stroke will be	2·63	cub. ft.
And at each revolution of the shaft	5·27	„
Which will give for each group of three compressors a volume of	15·81	„
At the normal velocity of sixty-five revolutions per minute this will give, for each group of three compressors, a theoretical volume of	1027·65	„
At a pressure of six atmospheres, which is the ordinary working pressure, this quantity will be reduced to	171·27	„
The actual volume, as proved by experience, will not amount to more than 70 per cent. of the theoretical volume, or	119·9	„

The experience gained at Airolo shows that Colladon's compressor, notwithstanding the complication of its parts, and the high velocity at which it is driven, does not require more repairs than the ordinary machines with water columns, which are driven at a much lower velocity; while the amount of its effective work will be fully equal to theirs. It is therefore superior to these latter, as, on account of its greater velocity, it is capable, with a smaller diameter and shorter stroke, and a consequent proportionate reduction in the first cost, of furnishing the same quantity of air at a given pressure. It also possesses the advantage of being able, with a slightly increased velocity, to furnish volumes of air greatly in excess of the normal quantity. This advantage, which is altogether unattainable in a machine with water columns, on account of the great mass of water which has to be put in motion, belongs, however, to all those direct-acting compressors in which the velocity can be increased in proportion as the cooling of the air is more completely carried out. The importance of this advantage can hardly be overrated.

With regard to the complication of its construction, this exists only in the means adopted for carrying on the circulation of the water in the interior of the piston and the piston rod; and although these means of cooling may be indispensable in those cases in which we are precluded from adopting the more simple, direct, and efficient method of cooling by the water jets, as commonly used for compressing gas, it seems to be proved by the experience at Airolo, where the circulation of the water in the piston has not been maintained, that up to a velocity of sixty-five revolutions a minute, the water jets suffice perfectly for maintaining the temperature within those limits which are favourable to the proper working of the apparatus. If this circulation be abolished, the machine will become one of the most simple, and, on account of its other advantages, the best of all air-compressors.

A series of four sizes of these compressors are manufactured. The compressor itself is, with the exception of its dimensions and some few matters of detail, the same as that which we have just described. It consists of a horizontal double-action cylinder, the piston of which is actuated either by a connecting rod, crank, belt, or toothed gearing, when the power is derived from an independent motor; but when the motor forms a part of the apparatus, the motor cylinder is placed on the same bed-plate and in line with the compressor cylinder, and the two piston rods are coupled together in such a manner as to form but one rod. A fly-wheel connected to the piston rods by means of a connecting rod and crank, equalizes their motion; while a governor, placed upon a small air-

reservoir, into which the water carried over by the air flows, acts in such a manner upon the steam-supply pipe as to cause the velocity of the engine to vary according to the pressure of air which it may be desirable to maintain constant.

The first type A, which is the least powerful, has been designed for the purpose of supplying sufficient air to drive one large size rock-drill.

The second type B is sufficiently powerful to drive two of such drills.

Types C and D are formed by coupling two or three of type B, of which any number may be joined, in order to meet the requirements of those works in which a large quantity of air is required. As, however, type B is of itself sufficiently powerful to drive four Dubois-François rock-drills, it will generally be found the most useful and economical for employment in mines.

The following table gives the principal dimensions, theoretical and useful effect, power required, and first cost of each of the four types.

The prices given include bed-plate, connecting rods, cranks, pulleys, and fly-wheels, and a reservoir for the compressed air, in which the latter is deprived of the water previously used to cool it. The prices with engine include, besides the above, an automatic governor which regulates the velocity of the motor according to the pressure of the air in the reservoirs.

			Type A. One Cylinder.	Type B. One Cylinder.	Type C. Two Cylinders coupled.	Type D. Three Cylinders coupled.
Dimensions of the Compressors ..	Diameter of the piston		in. 10·63	in. 15·0	in. 15·0	in. 15·0
	Stroke of the piston		23·26	30·9	30·9	30·9
	Theoretical volume generated per minute at the mean velocity		cub. ft. 181·25	cub. ft. 240·43	cub. ft. 480·86	cub. ft. 721·29
	Revolutions per minute	Mean ..	83	60	60	60
		Minimum	41·5	30	30	30
		Maximum	124·5	90	90	90
	Corresponding velocity of the piston per second	Mean ..	ft. 5·0	ft. 5·0	ft. 5·0	ft. 5·0
		Minimum	2·5	2·5	2·5	2·5
		Maximum	7·5	7·5	7·5	7·5
Power required ..	Calculated for the different velocities at which the machine may be driven	Mean ..	H.P. 25	H.P. 50	H.P. 100	H.P. 150
		Minimum	12	25	50	75
		Maximum	36	75	150	225
Useful effect	Volume of air compressed to six atmospheres which the apparatus will furnish per minute, when driven at either velocity	Mean ..	cub. ft. 25·2	cub. ft. 33·6	cub. ft. 67·2	cub. ft. 100·8
		Minimum	12·6	16·8	33·6	50·4
		Maximum	37·8	50·4	100·8	151·2
Price of the Apparatus	Compressors arranged to be driven by an independent motor—steam or hydraulic		£ 290	£ 540	£ 1008	£ 1512
	Combined engine and compressors—the engines being horizontal and non-condensing, with variable expansion ..		900	1512	2700	4000

As the principal advantage possessed by compressors with direct action, and the one which often causes them to be chosen in preference to all others, lies in their being capable of being economically worked at velocities varying within wide limits, the machines described have been calculated and designed for a maximum piston speed of 7·5 feet per second; they may, however, be driven at any speed below this, the normal velocity depending upon the volume of air which it is

wished to compress per minute. In calculating the effective volumes in the above table, a loss of one-sixth of the theoretical value has been allowed.

Air-Compressors at the Blanzy Collieries.—At the Blanzy mines, where compressed air is employed on a large scale, there has been adopted for its production, a compressor with direct action, constructed by Revollier, Biétrix, and Co., of St. Etienne, which furnishes 423·8 cubic feet of air per minute, compressed to three atmospheres.

These compressors are composed of two horizontal cylinders, fixed in line with and upon the same bed-plate as the two steam cylinders, which are fitted with variable expansion on Mayer's system. The piston rods of the compressors and of the engines are joined by a coupling, the pins of which work in guides; the engine piston rods being attached by means of connecting rods and cranks to the two ends of the shaft carrying the fly-wheel, Fig. 243. By referring to Figs. 243 and 244 it will be seen that the cooling is produced by a current of water circulating through an external casing or jacket, as well as by the direct injection, at each end of the cylinder, of a jet of water under great pressure through an ajutage or rose pierced with very small holes. The suction and discharge valves are simple cast-iron clacks faced with leather, the seats being also of cast iron.

The principal dimensions of this compressor are as follows:

Diameter of steam cylinder	25·6 inches.
„ compressor cylinder	21·7 „
Stroke of pistons	63·0 „
Area of suction valves	59·0 sq. in.
„ discharge valves	47·74 „
Number of revolutions per minute	25
Velocity of the pistons per second	4·37 feet.
Theoretical volume generated by the compression piston at each stroke	13·5 cub. ft.
Which gives for each revolution of the two compressors	54·0 „
And for the two compressors, running at a velocity of twenty-five revolutions per minute	1350 „
This reduced to a pressure of three atmospheres will equal a theoretical volume of	450 „
In practice the actual volume will not amount to more than 90 per cent. of the theoretical	405 „

This compressor, which is more simple in its construction than Colladon's machine, may be employed in all cases where an economy in the first cost is not a matter of grave consideration; for though its velocity, which is almost double that of Sommeiller's compressor, combined with its larger size, permits it to furnish three or four times the quantity of air given by the latter, without any increase in its cost, its dimensions and mode of direct action prevent it from being driven at velocities equal to Colladon's compressor; in this latter also, the water jet being more finely divided into spray, the cooling of the air is obtained with a much smaller volume of water, which of itself is equal to an increase in the duty of the machine.

Sturgeon's High-speed Compressor.—The chief object sought by Mr. Sturgeon in the design and construction of his high-speed air-compressing engine has been to increase the percentage of the useful effect obtained from the force applied. This object he has endeavoured to attain by the adoption of a new construction of inlet valves of his own invention, which allows him to run his compressor at high speeds, without danger of these valves becoming unreliable in their action, and without detriment to his machine, allowing for reasonable wear and tear.

The receiver and steam cylinder in this engine are cast in one piece, the air-compressor cylinder being bolted to the receiver on the side opposite to that on which the steam cylinder is placed, as

shown in Figs. 246 and 247, in which *a* is the air-compressing cylinder, *c* the steam cylinder, and *b* the receiver. A fly-wheel shaft *d* is carried by two pedestals at the other end of the bed-plate or receiver *b*, and to this shaft are keyed the fly-wheels *e e'*, one at each end; the crank-pins *f f'* on these fly-wheels are fixed at right angles to each other, and are connected in the usual way to the two cylinder pistons. Now, as in the compressing cylinder the pressure is smallest at the beginning of the stroke, and the greater portion of the work is done in the latter part of the stroke, whereas in the steam cylinder the pressure is greatest at the beginning of the stroke, and least at the end, the setting of the crank-pins at right angles to each other enables the steam crank-pin to be in its best position to meet the increasing resistance in a similar ratio. It is said that by this arrangement, and with equal cylinder diameters on both sides, the air-compressor has registered, at one and the same time, double the steam pressure of the other cylinder.

To meet the varying requirements of the air-driven machinery in the supply of air, the following arrangement has been adopted, by means of which the steam engine is enabled to vary its speed automatically, so that when the air-driven machinery is stopped, the air-compressor may likewise stop of its own accord. On the fly-wheel shaft *d* an eccentric *k* is placed, which, by working on to a combination of levers, is made to actuate the valve of the steam engine in such a manner as to lengthen or shorten the travel of the slide, according as the pressure in the receiver falls below or rises above the required degree, which will necessarily correspond to an increase or a slackening of speed. A plunger *q* fits air-tight in a recess made in the receiver *b*, and according as the pressure increases or diminishes, so will the plunger rise or fall, carrying with it in the same direction the fulcrum *o* of a lever *n*, whose centre *o* is accordingly raised or lowered in the guides *p p*. Motion is produced in this lever *n* round its fulcrum *o*, by its upper end being connected with the before-mentioned rod *m*. The valve lever *s*, working from the fixed centre *t*, has a projecting pin *r*, gearing into a corresponding groove cut along the length of the lever *n*, so that the to-and-fro movement of the lever *n* is imparted to the valve lever *s*. From this description it will be evident that the more the centre *o* rises, the more will the travel of the valve be shortened; in other words, the less steam will be admitted into the steam cylinder, whereupon a slackening of speed must ensue, and *vice versâ*. In order to regulate the pressure required in the receiver *b*, a sliding weight *u* is attached to the rod *m*, which, according to the position in which it is set, can be made to maintain the degree of pressure desired in the receiver. When the centre of the lever *n* comes opposite the pin *r* of the lever *s*, the motion of the latter is stopped, and the engine automatically comes to a stand.

In order to reduce the heating of the compression cylinder, it is enveloped by a cavity or tank, which is kept constantly filled with cold water. As this water becomes heated, it is used as feed water for the boiler, and thus a portion of the heat generated, which otherwise proves detrimental, is turned to some advantage. The nicety with which all the working parts of this machine are counterbalanced is evident from the fact, that with a speed of two hundred and twenty revolutions, or 440 feet a minute, no further foundation is required than a few wooden logs placed underneath, to keep the fly-wheels from touching the floor.

The construction of the air-cylinder valves, which form the chief innovation in this type of air-compressor, will be fully understood by a reference to the enlarged section, Fig. 248, and the following description: These valves are fixed in the cylinder covers, and are exactly similar at each end. the inlet valve *i i* is placed in the centre of the cylinder cover in the form of a circular ring. The cylinder piston is fitted at each end with stuffing boxes *h h*, which are securely packed to the piston,

so as to have a frictional hold thereon. The inner end of this stuffing box h is made to sit close on the inner surface of the cylinder cover when the two come in contact with each other. Owing to the frictional grip which this stuffing box has upon the piston, as the latter recedes from one end of the cylinder, the corresponding stuffing box becomes drawn in the same direction, till its travel is checked by the stop, shown in the figure, coming against the outside surface of the cylinder cover, when the piston completes the remainder of its stroke independently, while the air is drawn in to the full extent of the stroke. The return of the piston brings the inlet valve close on to its inner seating, thus preventing the air from escaping out again whilst it is being compressed. To prevent these valves from coming in violent contact on their inner seatings, when working at high speeds, the crank-pins are further so arranged that, at the moment of contact, the respective crank-pin is almost on its centre, or at its lowest speed, and the valve is thus brought gently on to its facings, without violent concussion. It is further evident that the opening of such inlet valves is altogether independent of the vacuum formed in the air-cylinder, inasmuch as they owe their actions to the driven piston. Moreover, the compressed air is here turned to account, in preventing the valve from opening until the piston has travelled sufficiently far to allow time for the delivery valves to close.

The delivery valves $j\,j$, it will be observed, are distributed over the whole inner surface of the cylinder covers, and are in direct communication with the receiver b, through the passage g. These valves are kept in close contact with their facings, partly by means of a spring thrusting inwards, and partly by means of the back pressure exerted on them by the compressed air in the receiver b. As soon as the pressure in the air-cylinders, acting on their inner surfaces, becomes greater than the counter-pressure before mentioned, the springs become compressed, or, in other words, the compressed air in the cylinder forces its way through the valve openings and the clear passage g, into the receiver b, to be there stored according to requirements. The back pressure on these delivery valves causes them to close again, and the inlet valves are then ready to open inwards. It will be seen that for the purposes of repairing or cleaning, these delivery valves can be removed without detaching any fast joints.

Air-Receivers.—As machines driven by compressed air in underground workings do not run continuously, the consumption of air is irregular; consequently it becomes necessary to store the air as it is received from the compression cylinders, in a reservoir of sufficient capacity to annul the effects of the irregularity existing between the production and the consumption. The minimum capacity of this reservoir should be twenty times the average consumption a minute, when only one compressor is employed; ten times when the compressors are two in number; and five times when there are three compressors. The form of the receiver or reservoir is a matter of small importance. Frequently an old boiler is used for this purpose. Every receiver should be provided with a pressure gauge, in order that the pressure of the contained air may be readily ascertained at any moment. The outlet from the receiver should be provided with a cock, for the purpose of cutting off communication between it and the conduit pipes. There should also be a discharge cock at the bottom of the receiver, for the purpose of removing the water which is carried in by the air, and which accumulates at the bottom. A neat and effective means of discharging the water has already been described in connection with the Sommeiller compressor, shown in Figs. 249 and 250. It is hardly necessary to remark that the receiver should occupy a situation in which it will not be liable to be exposed to heat, the action of which upon the contained air would occasion a loss of work.

Air-Conduits.—For the conveyance of compressed air from the reservoir to the points at which

the machines are required, both cast-iron and wrought-iron pipes are used. When cast iron is the material employed, the pipes are cast with a flange, and the joint is made by means of an indiarubber washer inserted between the flanges. In some cases, one flange is provided with a groove, and the other with a corresponding annular prominence, the edges both of this projection and of the groove being bevelled. To form the projection, the flange is turned down, and the groove is also cut in the lathe. The ring of indiarubber is placed in this groove, which is $\frac{1}{2}$ inch broad and $\frac{1}{4}$ inch deep.

Wrought-iron tubing is in many cases preferable, especially on account of its lighter weight. This tubing is usually manufactured in 14-feet lengths, and with an internal diameter of $3\frac{1}{4}$ inches. Such a length will weigh about 80 lbs. The joints in this case are made by means of flanges $7\frac{1}{2}$ inches in diameter, strongly brazed upon the ends of the tube, and pierced with four bolt-holes $\frac{3}{4}$ inch in diameter. In order to obtain the requisite degree of rigidity, great care is needed in putting on these flanges. Before applying them a groove is cut in the lathe in the thickness of the flange, and a copper ring of $\frac{5}{32}$ inch on the side inserted. This ring is, by the process of soldering, rendered solid with the flange and tube, and by that means a perfectly air-tight joint is made. In joining the tubes, an indiarubber washer is inserted between the flanges.

In certain situations, where rapid oxidation of the metal is likely to occur, an air-conduit may be composed of both cast and wrought iron pipes, each material being confined to the locality for which its qualities render it the more suitable. All air-pipes should, previously to their being put into use, be tested by hydraulic pressure up to ten atmospheres, and also by air pressure under water up to seven or eight atmospheres. By such means any latent defects in them are rendered apparent, and confidence in their resisting and retaining powers is created.

When a considerable length of air-piping is laid down, means must be provided to allow of expansion and contraction under the influence of changes of temperature. In underground workings, the temperature is sufficiently constant to justify a neglect of such precautions; though even there it is well to be prepared against a sudden rise of the temperature. But in the shaft and at surface, the conditions are different, and rollers and compensating joints become a necessity. A form of compensating joint that has been proved to act satisfactorily in practice is shown in Figs. 253 and 254. It consists of a tube of copper, of the same dimensions as the iron tubes, and bent into the form shown in the drawing. The flanges of this tube are applied in the same manner as those of the iron tubes. In practice, it has been found necessary and sufficient to insert one of these compensating joints at intervals of about 100 yards.

The tubing used to connect the machine drills with the fixed iron tubing is always flexible. The material used is indiarubber, and great thickness is given to the tubing to ensure strength. As a protection from injury caused by friction against the rough surfaces of the rock, such tubing is covered with coarse canvas. The internal diameter of the largest size used is 2 inches, and that of the smallest about $\frac{3}{4}$ inch.

Water Reservoirs.—In rock boring by machinery, the application of water greatly facilitates the operation by keeping the bottom of the hole free from the debris, and hence it is highly conducive to rapidity of execution. It has been proved by experience that the rate of boring in a dry and in a wet hole varies as $1 : 1 \cdot 5$; that is, it takes one and a half times as long to bore a hole dry, as to bore a hole with the assistance of water. Thus it is possible to reduce the time of boring by one-third. Moreover, the great heating produced in the borer bit by the blows upon hard rock causes a rapid deterioration of the tool, and hence it becomes necessary to change and to repair it more

frequently. Another great objection to dry boring is the production of a large quantity of fine dust, which is a cause of annoyance to the workmen, and of destruction to the packing and the rubbing surfaces of the machinery. For these reasons, a supply of water is desirable; and when the holes are inclined upwards it becomes necessary to inject the water into them with considerable force. For this purpose, water reservoirs are required. These reservoirs are constructed of galvanized iron, and are made of various dimensions, according to the conditions under which they will have to be used. They are filled through a funnel-cock, which being closed renders them air-tight. By means of a piece of tubing, the water reservoir may be placed in communication with the air-pipe, from which the requisite pressure is obtained; the water is directed into the bore-hole as a strong jet by means of another piece of flexible tubing provided with a suitable nozzle. When a heavy drill support is employed, capable of running upon tramways, the water reservoir may be conveniently fixed upon the support. But in other cases, there is a difficulty in using a reservoir so as not to be an encumbrance rather than a means to rapid progress. A water reservoir, used with the Darlington drill, is shown in Figs. 251 and 252.

Appliances for firing Blasting Charges.—In the foregoing sections, the machines, tools, and other appliances used in boring rock have been treated of. It now remains to describe those which are employed in firing the charges after they have been placed in the bore-holes. In this direction, too, great progress has been made in recent times. With the introduction of new explosive agents arose the necessity for improved means of firing them. Attention being thus directed to the subject, its requirements were investigated and its conditions observed, the outcome being some important modification of the old appliances and the introduction of others altogether new. Some of the improvements effected are scarcely less remarkable than the substitution of machine for hand-boring.

The means by which the charge of explosive matter placed in the bore-hole is fired constitutes a very important part of the set of appliances used in blasting. The conditions which any such means must fulfil are: (1) that it shall fire the charge with certainty; (2) that it shall allow the person whose duty it is to explode the charge to be at a safe distance away when the explosion takes place; (3) that it shall be practically suitable, and applicable to all situations; and (4) that it shall be obtainable at a low cost. To fulfil the second and most essential of these conditions, the means must be either slow in operation, or capable of being acted upon at a distance. The only known means possessing the latter quality is electricity. The application of electricity to this purpose is of recent date, and in consequence of the great advantages which it offers, its use is rapidly extending. The other means in common use are those which are slow in operation, and which allow thereby sufficient time between their ignition and the explosion of the charge for a person to retire to a safe distance. These means consist generally of a train of gunpowder so placed that the ignition of the particles must necessarily be gradual and slow. The old, and still commonly employed, mode of constructing this train was as follows: An iron rod of small diameter and terminating in a point, called a "pricker," was inserted into the charge and left in the bore-hole while the tamping was being rammed down. When this operation was completed, the pricker was withdrawn, leaving a hole through the tamping down to the charge. Into this hole a straw, rush, quill, or some other like hollow substance filled with gunpowder was inserted. A piece of touch-paper was then attached to the upper end of this train, and lighted. When the train became ignited, the powder being confined in the straw, except at the upper end, burned slowly down and fired the charge, the

time allowed by the touch-paper and the train together being sufficient to enable the man who applied the match to retire to a place of safety. This method of forming the train does not, however, satisfy all the conditions mentioned above. It is not readily applicable to all situations. Moreover, the use of the iron pricker may be a source of danger; the friction of this instrument against silicious substances in the sides of the bore-hole or in the tamping has in some instances occasioned accidental explosions. This danger is, however, very greatly lessened by the employment of copper or phosphor-bronze instead of iron for the prickers. But the method is defective in some other respects. With many kinds of tamping, there is a difficulty in keeping the hole open after the pricker is withdrawn till the straw can be inserted. When the holes are inclined upwards, besides this difficulty, another is occasioned by the liability of the powder constituting the train to run out on being ignited. And in wet situations, special provision has to be made to protect the trains. Moreover, the manufacture of these trains by the workmen is always a source of danger. Most of these defects in the system may, however, be removed by the employment of properly constructed trains. One of these trains or "fuses" is shown in Fig. 255.

Safety Fuse.—Many of the defects pertaining to the system were removed by the introduction of the fuse invented by Bickford, and known as "safety fuse." The merits of this fuse, which is shown in Fig. 256, are such as to render it one of the most perfect of the slow-action means that have yet been devised. The train of gunpowder is retained in this fuse, but the details of its arrangement are changed so as to fairly satisfy the conditions previously laid down as necessary. It consists of a flexible cord composed of a central core of fine gunpowder, surrounded by hempen yarns twisted up into a tube, and called the countering. An outer casing is made of different materials according to the circumstances under which it is intended to be used. A central touch thread, or in some cases two threads, passes through the core of gunpowder. This fuse, which in external appearance resembles a piece of plain cord, is tolerably certain in its action: it may be used with equal facility in holes bored in any direction; it is capable of resisting considerable pressure without injury; it may be used without special means of protection in wet ground; and it may be transported from place to place without risk of damage.

In the safety fuse, the conditions of slow burning are fully satisfied, and certainty is in some measure provided for by the touch thread through the centre of the core. As the combustion of the core leaves in the small space occupied by it a carbonaceous residue, there is little or no passage whatever left through the tamping by which the gases of the exploding charge may escape, as in the case of the straw trains. Hence results an economy of force. Another advantage offered by the safety fuse is, that it may be made to carry the fire into the centre of the bursting charge if it be desired to produce rapid combustion. This fuse can also be very conveniently used for firing charges of compounds other than gunpowder, by fixing a detonating charge at the end of it, and dropping the latter into the charge of the compound. This means is usually adopted in firing the nitro-glycerine compounds, the detonating charge in such cases being generally contained within a metallic cap. In using this fuse, a sufficient length is cut off to reach from the charge to a distance of about an inch, or farther if necessary, beyond the mouth of the hole. One end is then untwisted to a height of about a quarter of an inch, and placed to that depth in the charge. The fuse being placed against the side of the bore-hole with the other end projecting beyond it, the tamping is put in, and the projecting end of the fuse slightly untwisted. The match may then be applied directly to this part. The rate of burning is about two feet a minute.

Safety fuse is sold in coils of 24 feet length. The price varies according to the quality, and the degree of protection afforded to the train.

Electric Fuses.—The employment of electricity to fire the charge in blasting rock offers numerous and great advantages. The most important, perhaps, is the greatly increased effect of the explosions when the charges are fired simultaneously. But another advantage, of no small moment, lies in the security from accident which this means of firing gives. When electricity is used, not only may the charge be fired at the moment desired after the workmen have retired to a place of safety, but the danger due to a miss-fire is altogether avoided. Further, the facility afforded by electricity for firing charges under water is a feature in this agent of very great practical importance. It would, therefore, seem, when all these advantages are taken into account, that electricity is destined to become of general application to blasting purposes in this country, as it is already in Germany and in America. Hence it is desirable to briefly describe in this work the means by which this agent is brought into use, in so far as these means constitute the instruments commonly employed.

An electric fuse consists of a charge of an explosive compound suitably placed in the circuit of an electric current, which compound is of a character to be acted upon by the current in a manner and in a degree sufficient to produce explosion. The mode in which the current is made to act depends upon the nature of the source of the electricity. That which is generated by a *machine* is of high tension, but small in quantity, whereas that which is generated by a *battery* is, on the contrary, of low tension, but is large in quantity. Electricity of high tension is capable of leaping across a narrow break in the circuit, and advantage is taken of this property to place in the break an explosive compound sufficiently sensitive to be decomposed by the passage of the current. The electricity generated in a battery, though incapable of leaping across a break in the circuit, is in sufficient quantity to develop a high degree of heat. Advantage is taken of this property to fire an explosive compound by reducing the sectional area of the wire composing a portion of the circuit at a certain point, and surrounding this wire with the compound. It is obvious that any explosive compound may be fired in this way; but for the purpose of increasing the efficiency of the battery, preference is given to those compounds which ignite at a low temperature. Hence it will be observed that there are two kinds of electric fuses, namely, those which may be fired by means of a machine, and which are called "tension" fuses, and those which require a battery, and which are known as "quantity" fuses.

In the tension, or machine fuses, the circuit is interrupted within the fuse case, and the priming, as before remarked, is interposed in the break; the current, in leaping across the interval, passes through the priming. In the quantity, or battery fuses, the reduction of the sectional area is effected by severing the conducting wire within the fuse case, and again joining the severed ends of the wire by soldering to them a short piece of very fine wire. Platinum wire, on account of its high resistance and low specific heat, is usually employed for this purpose, but iron is sometimes used. The priming composition is placed around this fine wire, which is heated to redness by the current as soon as the circuit is closed.

The advantages of high tension lie chiefly in the convenient form and ready action of the machines employed to excite the electricity. Being of small dimensions and weight, simple in construction, and not liable to get quickly out of order, these sources of electricity are particularly suitable for use in mining operations, especially when these operations are entrusted, as they usually are, to men of no scientific knowledge. Moreover, as the means of discharging the machine may be

removed until the moment when it is required, this mode of firing offers greater security than the battery. Also by employing a current of high tension, a large number of shots may be fired simultaneously in single circuit with greater certainty than is obtained with a battery, unless the power of the latter be accurately calculated for the number of fuses in circuit and the thickness of the platinum wire used. Another advantage of high tension is the small effect of line resistance upon the current, a consequence of which is that mines may be fired at any distance from the machine, and through iron wire of very small section. A disadvantage of high tension is the necessity for a perfect insulation of the wires.

When electricity of low tension is employed, the insulation of the wires needs not to be perfect, so that leakages arising from injury to the coating of the wire are not of great importance. In many cases, bare wires may be used. Other advantages of low tension are, the ability to test the fuse at any moment by means of a weak current, and an almost absolute certainty of action. For this reason, it is usually preferred for torpedoes, and important submarine work. On the other hand, the copper wires used must be of comparatively large section, and the influence of line resistance is so considerable that only a small number of shots can be fired simultaneously when the distance is great. Moreover, as the number of fuses is increased, the power of the battery must be augmented by adding to the number of its cells, so that for ordinary mining operations the battery becomes large and unportable. But the chief disadvantage of the battery lies in the fact of its requiring a liquid to excite the current, and the consequent careful attention and delicate handling which the elements require. This defect may, however, be removed to some extent by a suitable form of the battery.

The details of the construction of an electric fuse may be varied greatly. A sectional view of one of André's tension fuses is shown in Fig. 257, and an outside view in Fig. 258. The central part consists, in one class of fuses manufactured, of a piece of guttapercha covered wire doubled, and the two portions twisted tightly together. The loop thus formed is stripped of the insulating material and cut through to make the interruption. Around these wires is a casing of a water-resisting compound, and over this is another casing of paraffined paper. Above the terminals, that is, the severed ends of the wire, is a chamber of peculiar form to receive the priming compound. This chamber, after the priming has been put in, is closed with the compound. The whole fuse thus constructed is sufficiently small to pass easily into the tube of a guncotton or a dynamite detonator. The electric current, in leaping across the interruption at *a*, passes through that portion of the sensitive compound which occupies the interval, and fires it. In André's quantity fuse, shown in Figs. 259 and 260, a similar mode of construction is adopted; but in this fuse, the interval between the ends of the wire is made wider, and is bridged over by a piece of fine platinum wire. The current in passing heats this wire to redness, and thereby fires the priming compound which is placed round it. This fuse is also capable of being inserted into the tube of a guncotton or a dynamite detonator.

Tension fuses have hitherto been, except when newly made, somewhat uncertain in their action, especially when used in warm climates. The defect is due mainly to the influence of moisture, particularly when combined with heat, and to the shocks and vibrations to which the fuses are necessarily subjected during transport. Heat and moisture cause decomposition to take place in the priming, especially when the latter consists of unstable elements; and shocks and vibrations loosen the mass of priming between the terminals, an effect that is very destructive to its sensitiveness.

To remove these sources of injury, the priming composition in André's fuse is hermetically enclosed within an internal casing of a material that is perfectly impervious to air and moisture, and

a bad conductor of heat, so that climatal influence cannot affect it in any degree. Fuses thus made have been immersed in warm water for weeks without suffering the slightest deterioration, and they have been fired beneath a head of 70 fathoms of water without a failure, even when subjected to this great pressure for a considerable time. They are, therefore, peculiarly suitable for subaqueous blasting, and for use generally in warm and moist climates. A special disposition of the priming composition has been adopted to prevent the injury arising from shocks, and this source of injury is still further guarded against by forcing in the priming under considerable pressure. Arrangements also are adopted for ensuring regularity, an essential condition when a number of fuses have to be fired simultaneously in single circuit.

The quantity fuses, illustrated, possess the following important advantages:—1. The diameter of the platinum wire is such as will give a high degree of sensitiveness, a condition which renders small battery power sufficient. 2. The length of the platinum wire is kept absolutely uniform, a condition of very great importance when several fuses are to be fired simultaneously. 3. The priming composition is perfectly protected from atmospheric influences and from moisture, so that these fuses are peculiarly suitable for blasting in very wet ground, and for submarine work. And 4. The size and form of the fuse are such as to admit of its easy introduction into the charge.

The wires which lead from the fuse up through the tamping above the charge, and called for that reason the shot-hole wires, must be "insulated," that is, covered with some material capable of preventing the escape of the electricity. Various materials are used for this purpose; the best is indiarubber, but its expensive character is a serious obstacle to its common use for shot-hole wires. Guttapercha is the next most suitable material, and, as it is comparatively cheap, it is largely employed in blasting under water, and in very wet ground. When guttapercha-covered wires are used, they are, in André's fuses, simply a continuation of those within the fuse, as shown in the drawings. But even guttapercha is too expensive for ordinary use. A much cheaper substitute is found in paper. When this material is used as an insulator, the wires are cemented between two strips about half an inch broad. These "ribbons," as they are called, are then dipped into some resinous substance to protect them from water. They are attached to the bared ends of the guttapercha-covered wires projecting from the fuses. Fig. 261 shows a ribbon in which the positions of the wires are indicated by dotted lines. For ordinary blasting operations, these ribbons are very suitable. Another insulating material employed is wood. A lath of this material, $\frac{1}{4}$ inch thick and $\frac{3}{8}$ inch broad, receives a narrow groove along its edges. Into those grooves the wires are placed, and the fuse with its detonator is fixed to the end of the stick. When fitted with André's fuse, the sticks are covered, to improve the insulation. The stick with the wires and fuse attached is called the "blasting stick;" it will be found illustrated in Fig. 262. The rigidity of the stick is found by miners to afford great facility for placing the fuse in the charge, an advantage that leads them to prefer this means of insulation.

Electrical Machines.—For the excitation of electricity in a state of high tension, two kinds of machines are used. In one kind, the current is excited by the motion of an armature before the poles of a magnet; in the other kind, the electricity is excited by friction and stored in a condenser, to be discharged by special means. The magnetic machines are the more simple in construction and the more constant in their action. But they generate only a small quantity of electricity, so that only a small number of fuses can be fired simultaneously in single circuit. By using the divided circuit, however, a very large number may be fired, if the machine be of the rotative class. The

friction machines generate a larger quantity of electricity, and therefore are capable of firing a larger number of fuses in single circuit than the magnetic machines. But they are far less constant in their action than the latter, a defect of grave practical importance. For the excitation of electricity in a state of low tension, batteries are employed in which chemical means are made use of to generate a current. These apparatus require a liquid to promote their action.

Breguet's Magnetic Firing Machine.—The simplest form of magneto-electric machine in common use is that known as "Breguet's Exploder," illustrated in Figs. 263 and 264. It is not of the rotative class, and is, therefore, unsuitable for firing a large number of fuses in divided circuit. But if not more than five or six be required to be fired simultaneously, it will be found to be the most convenient yet made. In Breguet's machine, the induction coils are placed upon bars of iron constituting a continuation of the arms of the magnet. The latter is fixed upon a base of wood, X X Y Y. Against the bars of soft iron upon which the coils are placed presses the armature A′ B′; this armature is fixed upon the lever E F P, which turns about a horizontal axis E F. When this lever is pressed down by a blow upon the knob P, the armature is withdrawn from the coils, but remains parallel with them. The lever is, moreover, provided with a spring H I, which descends with the point H in the lever. While the armature A′ B′ is in contact with the coils, the free end I of the spring presses against the lower end of the screw Q, the support of which is in communication with the wire J K. But when the lever is depressed, the spring descends also, until, at a certain point, it is separated from the screw. When this separation takes place, the short circuit K J I H F G K′ is interrupted, and the current is then forced to pass into the long circuit K L N D′ N′ L′ K′, in which the fuse is placed. The point at which interruption shall take place is regulated by raising or lowering the screw Q. This point should be a little above that at which the spring stands when at the end of its stroke, because then the intensity of the current is at its maximum. When the hand is removed from the knob P, a spring beneath the lever, aided by the attraction of the magnet, forces the armature back into contact with the poles A B. A safety bolt, S T, is pushed under the lever to prevent accidental discharges. The whole of the apparatus, with the exception of the knob P and the terminals N, is enclosed with a wooden case.

The leading and the return wires being fixed to the terminals N, and the fuses included in the circuit, the latter are fired by striking a sharp blow upon the knob P.

For firing a large number of fuses, Siemen's dynamo-electric machine is the most suitable. This is a rotative machine, and is, therefore, adapted to the divided circuit.

André's Friction Machine.—Friction machines possess the advantage of generating a larger quantity of electricity than the magnetic machines, with a tension sufficient to carry the current over wide interruptions in the circuit. By reason of this property, they are capable of firing a large number of fuses in single circuit, an advantage that renders them very suitable for use in industrial operations. Unfortunately, however, they are inconstant in action, in consequence of the wear of the rubbing surfaces, and, chiefly, the influence of moisture in the atmosphere. Magneto-electric machines are also affected by this influence, but in a lower degree. The difficulty lies in effectually excluding the air so as to isolate the atmosphere inside the machine from that on the outside. This difficulty is created by the necessity which exists for communicating with the inside. One of the rubbing surfaces must be set in motion from the outside, and through the aperture traversed by the winch handle usually adopted for this purpose the air enters. And in addition to this, there is generally some contrivance for effecting the discharge, which contrivance requires a second opening

into the machine. In some of the American frictional machines, this second opening is avoided by means of an arrangement whereby the discharge of the condenser is effected by simply reversing the motion of the winch handle. André's machine is constructed to discharge itself as soon as a sufficient quantity of electricity has been generated. This, besides the advantage of rendering a communication with the inside unnecessary, constitutes an important quality when the machine is used by an inexperienced or a careless operator, since it cannot be made to deliver an insufficient charge, nor can it be injured by overcharging.

This machine is illustrated in Figs. 265 and 266. The outside dimensions are a little less than a foot cube, so that it is easily portable. The case is double, to exclude moisture, and the handle communicating with the outside is made to pass through stuffing boxes, for the same purpose. The exciting surface is furnished by a cylinder or by a plate of ebonite, upon which the rubbers press. The collectors and the rubbers are in electrical communication with a condenser placed inside the cylinder, or in the bottom of the box beneath the plates, to economise space. When, by a continued turning of the winch handle on the outside, the tension of the charge has been made sufficient, the electricity leaps to the point P, and the fuses, included in the circuit connected to the terminals on the outside of the box, are fired.

A good frictional machine, much used in Germany and in England, is Bornhardt's, the maker being A. Bornhardt of Brunswick. This firing machine, which will be found illustrated in Figs. 267 to 269, with a fair amount of care, continues efficient under the ordinary conditions of mining. The circular friction-plate F is of ebonite, and turns upon an iron axle *a*, which is furnished with a pinion *b*. This pinion is driven by a toothed wheel *c* four times its diameter, to give velocity to the plate. The driving wheel *e* is turned by means of a winch handle *d* on the outside of the wooden case or box in which the parts are contained. The rubbers R are held up against both sides of the plate by springs H. The collectors J collect the electricity as it is excited, and convey it to the condenser L. This condenser is set upon a wooden base fixed to the casing; the side next the plate is covered with a guard or shield of vulcanised indiarubber, to prevent a discharge of electricity from the plate to the outer covering. The discharge of the condenser is effected by means of the conductor G, which is pressed into contact with it through the medium of the button K, as shown by the dotted lines, against the force of a spiral spring which tends to hold the conductor away from the condenser. The ring D is in metallic communication with the outer surface of the condenser. In order to ascertain the condition of the machine, a scale of fifteen metallic buttons is provided on the outside at X, which scale may be put in communication with the poles C and D of the machine by means of brass chains, as shown in the drawings. If, after fifteen or twenty turns of the handle, according to the more or less moist state of the atmosphere, the spark leaps the breaks in the scale when the knob K is pressed in, the machine is in a good working condition. The outside dimensions of the wooden casing are 20 inches in length, 7 inches in breadth, and 14 inches in depth; the weight does not exceed 20 lbs.

To fire the charges by means of this machine, the leading wire is hooked on to the ring C, and the return wire to the ring D, the other ends being connected to the fuses. The handle is then put on, and from ten to twenty turns given briskly to excite the electricity. The knob K is then pressed in, and the discharge takes place.

To give security to the men engaged, the handle *d* is designed to be taken off when the machine is not in actual use, and the end of the machine, into which the circuit wires are led, is made to close

with a lid Q and lock, the key of which should always be in possession of the person in charge of the firing operations.

The frictional machines used in America are chiefly Mowbray's, and that known as Laflin and Rand's. Both of these are highly esteemed; but their cost is considerably greater than that of Bornhardt's. They are discharged by turning the handle a quarter turn backward, a device which removes the necessity for two apertures of communication with the interior of the machine.

Batteries.—Batteries are required for firing quantity fuses. The current is excited by chemical action, a means that necessitates the use of a liquid. The attention which a battery demands constitutes a practical disadvantage of considerable importance. Numerous forms of battery are in use, several of which are suitable for blasting purposes. As they differ in no essential feature from those used for telegraphic purposes, it does not seem desirable to describe any one of them in this place.

Cables.—Cables are used to connect the fuses with the machine or the battery. They generally consist of several strands of copper wire well insulated with guttapercha or with indiarubber, and protected from injury by a coating of hemp or of tape. Two cables are needed to complete the circuit; the one which is attached to the positive pole of the machine or the battery, that is, the pole through which the electricity passes out, is distinguished as the "leading wire," and the other, which is attached to the negative pole, that is, the pole through which the electricity returns, is described as the "return wire." The most convenient form of cable is that which contains both the leading and the return wires under one hempen covering; such a cable is shown in Figs. 270 and 271.

Cable Box.—It is found convenient to have the cable wound upon a reel, and the reel contained in a box. Such a box is shown in Figs. 269 and 270. It is a wooden box fitted with a reel, which may be turned by a winch handle from the outside. The cable upon the reel is in metallic connection with two brass eyes on the upper edges of the box. The machine may thus be connected, without removing the cable from the reel, by simply attaching a connection to those eyes. The lower portion of the box has a drawer divided into several compartments for fuses, connecting wire, small tools, and necessaries. With the machine, it constitutes a complete set of electrical blasting apparatus.

HAND TOOLS.—The hand tools of the miner consist chiefly of the shovel, the pick, the wedge, and the hammer.

Shovels.—The shovel is a well-known and very serviceable tool, the use of which is to collect and remove into corves, tubs, barrows, or carts, the rock that has been loosened by other means. It consists essentially of a "plate" for passing under and retaining the loosened material, and a wooden handle to which the plate is fixed. To give lightness and stiffness to the plate, and at the same time to enable it to pass readily beneath the rock and to retain its hold, it has received several forms, according to the use to which the tool is to be applied; and to allow it to be used in more or less confined spaces, the handle has been made of various lengths. The plate is always of iron, and the front edges are steeled. Stiffness and carrying capacity are obtained by making the plate slightly concave. The upper portion, or "shoulder" of the plate, is provided with "straps" or "ears" to receive the handle; and at the part where it joins the "straps" it is buckled upwards, to give strength. This part is called the "crease." The handle or helve is always of ashwood, and is circular in section. It terminates in a crutch-handle or hilt, a form which is preferred by miners to the common D or "eyed" handle. To lessen the necessary degree of stooping, the handle is set

at an angle with the plate. The sizes of shovels are distinguished by the width of the plate, measured in its widest part; they vary from 10 inches for heavy work, to 16 inches for light work, such as shovelling coal or loose earth. The strain upon the shovel when in use is mainly thrown upon the crease and the top strap, and it is at this part that they yield by the parting of the strap. Strength in the strap and the crease is, therefore, a requirement in a shovel.

The form of shovel used for gravel is that shown in Fig. 274. The plate is 10 inches wide, and the "mouth" or entering part is pointed so as to form two edges. This form renders it very suitable for entering closely compressed or heavy ground. The handle is 30 inches long, and is set at an angle of about 150° with the surface of the plate.

Fig. 275 represents a "frying-pan" filling shovel, as used in the north of England and in some other districts. The plate is nearly circular, with a short point, and the edges are turned up to give it concavity. The breadth is 14 inches, and the length 16 inches; the handle is 24 inches long, and is set at an angle of 142° with the plate. The weight of this tool is 7 lbs. 14 oz.; it is well adapted for loading coal into tubs, and it is very extensively employed at collieries.

Fig. 276 represents a "round-mouthed" filling shovel, which is very generally employed for shovelling loose stuff not too heavy. The plate is 16 inches wide and 15 inches long; the handle is 23 inches in length, and is set at an angle of 147° with the plate. The weight of this tool is also 7 lbs. 14 oz. Fig. 277 represents a "sinking shovel," $11\frac{1}{2}$ inches × 14 inches, the handle of which is 23 inches in length.

For use in clay ground, the "clay spade," shown in Fig. 278, is used. The plate of the spade is long and narrow, and has a square mouth. Sometimes the plate is curved so as to form a portion of a cylinder, as shown in the figure. When of this form it is often called a "grafting spade." The clay spade is used by forcing it into the ground with the foot placed upon the shoulder, and to form a convenient tread a piece of iron is riveted upon the shoulder. This tool is much used in soft or clay ground.

The shovel is the only tool which is never made at the mine: it is always purchased ready made, and when broken it is seldom capable of being repaired. The cost of gravel shovels, 10 in., 11 in., and 12 in. wide, is from 25*s.* to 35*s.* a dozen; all steel, from 60*s.* to 70*s.* Frying-pan and round-mouthed filling shovels cost, according to size, from 35*s.* to 48*s.* a dozen; all steel, round mouths, from 45*s.* to 60*s.*; and clay spades, 12 in. × $6\frac{1}{2}$ in., about 35*s.* a dozen.

Picks.—The pick, mandril, or hack, as it is variously named, is the most important tool of the miner. Its use is to loosen masses of rock, or to chip away small fragments. It consists of an iron head formed of two arms, and a wooden handle or helve fitted into an eye in the middle of the head or stem. The arms are steeled at the tips, and are either pointed or chisel-edged, according to the work required of the tool. When pointed, the point is formed by a square taper. Such wedge-shaped extremities enable the arm to penetrate the joints of fissured rocks, or between the laminæ of shaly rocks. When the tip of one arm of the pick has been forced into the rock, it is used as a lever to fracture the mass by pressing or prizing upon the helve. Thus the action of the pick combines that of the hammer, the wedge, and the crowbar or lever. It acts as a hammer, in delivering a blow; as a wedge, in penetrating and disrupting the rock; and as a lever, in forcing out large masses. These several actions must be borne in mind when considering the form and construction of a pick. With the chisel edge it is very frequently used to chip off fragments of rock, as in dressing the sides of an excavation. In this case, it combines the action of the chisel and the hammer.

In using the pick as a lever, the strain is thrown on the helve in the eye, and the helve yields in that part by "wincing," that is, by a crushing of the fibres. To provide against this wincing, the bearing surface at each end of the eye should be made as long and as wide as possible. It is obvious that the sharper the edges of the feather, that is, the widened portion of the helve that fits into the eye, the greater will be the tendency to wince. Wedging the helve very tightly into the eye, so as to make it press against the cheeks, also lessens the liability of the fibres to yield. Many devices against wincing have been adopted, the most effective of which, however, consist in lengthening the eye in the direction of the helve, in flattening the edges of the feather, and in providing the helve at that part with an iron strap or ring.

The pick-head is usually made of wrought iron. It consists of a central part called the "eye," made to receive the helve, and two shanks or stems. The sides of the eye are spread out to form cheeks, against which the sides of the helve may be firmly wedged. Generally the shanks are square in section, and their size varies in dimension from $\frac{3}{4}$ inch in light picks, to $1\frac{1}{8}$ inch in heavy picks near the eye, diminishing gradually towards the point. Sometimes the section of the shank is $1\frac{1}{4}$ inch $\times$ 1 inch, or $1\frac{1}{8}$ inch $\times$ $\frac{7}{8}$ inch, the longer side being in the direction of the helve, to give greater strength for prizing. Frequently, when the section is square, the edges are chamfered down, and in some cases the chamfering is carried so far that the section approaches the octagonal form. The ends of the shanks are steeled, and brought, as before remarked, either to a point or a cutting edge. The weight of the head varies from 2 lbs. to 7 lbs., according to the nature of the work to which the tool is to be applied, the difference of weight being caused by the larger section, and the greater length of the shanks required for certain purposes. The helve is of ashwood, and consists of two portions, the haft and the feather; the latter portion is inserted into the eye, and fixed by wedging. The length of the helve also varies according to the nature of the work to be performed, from 24 inches to 34 inches.

Pick-heads are made straight, curved, or anchored. Straight-headed picks assist the reach, and are more suitable for getting into corner work than the curved or the anchored forms. They are always preferred for long-reaching or over-hand work. When curved, the head is said to "sweep," and such a form is preferred for under-hand work, the sweep causing the tool to fall into its work better than it would do if the head were straight. The degree of curvature is always slight. Sometimes, instead of curving the shanks, they are made straight and converging to the eye. This form is described as the anchored, and is very common in the north of England.

The tips of the shanks are sharpened on an anvil, and tempered to the requisite degree of hardness. The form of the cutting edge will be determined by the nature of the work to be performed. For hard ground the four-sided pyramid point is generally the most suitable. The rate of taper in such a case will also be determined by the character of the work. A quick taper or "bluff" point is stronger than a slow taper or "slim" point; but if the point is very bluff it will not penetrate the rock readily. When the tool is required to work in a narrow slit, it is obvious that the point must be slim, even if the nature of the rock is such as to require a bluff point, since the pick-head cannot be turned sufficiently to enable the bluff point to catch the side of the cut; and such a circumstance would soon cause the sides to come together, or "cut out," as it is termed. As the bluffness of the point under such conditions is mainly dependent upon the length of the head, the latter is usually shortened to increase the bluffness. This relation between the rate of taper of the point and the

length of the head is evident, for the shorter the head the more obliquely it may be turned in a narrow cut. The pyramid point is very generally used for holing coal; that is, for cutting a narrow slit in the seam; but the conditions existing in this case seem rather to require a chisel edge. The operation of holing consists in *chipping*, and for such a use the point is not suitable. It is somewhat remarkable that this form of cutting edge should still be used by hewers. With the exception of this case, whenever the pick is to be used for chipping the rock, the chisel edge is adopted. The chisel edge is also suitable for penetrating the joints of rocks, or between their laminæ, as before remarked, so as to disrupt them by acting as a wedge, or to dislodge them by acting as a lever.

Picks may be divided, according to the nature of the work to which they are applied, into three classes, and described as "stone picks," "holing picks," and "cutting picks." The first of these are used in rock only, and to render them suitable for such heavy work they are made very strong and heavy. Holing picks are used for undercutting coal, and are used either in the coal or in the underclay. In using them, they are swung horizontally. Cutting picks are swung vertically for downward cutting, and are used for cutting or shearing off the coal at the side of the stall or face, so as to divide the seam on each side after it has been "holed," for the purpose of causing it to fall. To avoid wasting the coal, these side cuts are made as narrow as possible. Cutting picks have a slim point, and are sometimes made slightly heavier than the holing picks. Various forms are given to picks by continental nations, but the following are almost exclusively employed in Great Britain and in America.

Fig. 279 represents a holing pick in common use in South Wales. The head is straight, and 18 inches in length from tip to tip. The helve is $33\frac{1}{2}$ inches long, and the weight of the whole tool, fitted as shown, is 3 lbs. 8 oz. The points of this pick are somewhat bluff.

Fig. 280 is a cutting pick used with the former. The head is straight, as in the holing pick. The length, however, is somewhat less, being 17 inches instead of 18 inches, and the helve is only $20\frac{1}{2}$ inches in length. The weight of this tool complete is 2 lbs. 14 oz. The shanks of the pick in this case taper directly from the centre to the points, which it will be observed are slim.

The stone picks used in the same districts have curved heads, and are of considerably larger dimensions. Fig. 281 represents a "bottom pick," that is, a pick used for cutting the floor or thill of the coal seam. The head is $21\frac{1}{4}$ inches in length, and the helve $30\frac{1}{2}$ inches. The weight of this tool is 3 lbs. 3 oz. The shanks in this case are provided with a chisel head 1 inch wide, one edge being horizontal and the other vertical.

Fig. 282 represents a stone pick, the head of which is 24 inches in length, and the helve $30\frac{1}{2}$ inches. The shanks are octagonal in section, and terminate, one in a wedge point and the other in a chisel edge. The weight of this tool is 9 lbs. 5 oz.

Fig. 283 represents a holing pick as used in North Wales. The head is 18 inches in length, and the upper side has a strong curvature or sweep. The cheeks are V-shaped, and the shanks terminate in chisel edges. The length of the helve is 28 inches, and the weight of the whole tool 2 lbs. 10 oz. The cutting pick used with this holing tool is of a similar form, but has less sweep. It is also slightly heavier, and has slim points.

Fig. 284 is a heading pick used in the same locality. The head is $16\frac{1}{4}$ inches in length, and has a top sweep only. The cheeks are V-shaped, and the shanks taper regularly from the eye. The

helve is $27\frac{1}{2}$ inches in length, and the weight of the tool is 3 lbs. A somewhat heavier form of this pick is used for dead work, and is called a "driving," or "metal driving" pick. It has a head $17\frac{1}{4}$ inches in length, a helve $27\frac{1}{2}$ inches long, and weighs 3 lbs. 10 oz.

Fig. 285 represents the form of coal picks common in the north of England. The head is $17\frac{1}{2}$ inches in length; the lower side is straight, but the upper side forms two inclined planes. In plan, the head is a regular lozenge-shaped figure, diminishing gradually from the eye to the points. The cheeks are semicircular and very small. The length of the helve is 32 inches, and the weight of the tool is 4 lbs. 5 oz.

Fig. 286 is similar to the preceding, except that the head is anchored, a form much in favour in the northern coal fields. The shanks in this case meet at an angle of 155°. The length of the head is 18 inches, that of the helve 32 inches, and the weight of the whole is 4 lbs. 5 oz.

Fig. 287 represents a stone pick of the same district. The head is slightly anchored, and is provided with tapered V-shaped cheek-pieces. The angles are deeply chamfered or bevelled, so as to give an octagonal section. Sometimes, however, the section is square: The shanks terminate in four-sided pyramidal points. The length of the head is $19\frac{1}{4}$ inches, that of the helve 30 inches, and the total weight of the tool 7 lbs. Frequently these stone picks are made stronger, the length of the head being increased to 23 inches, and the weight to 8 lbs.

An improved form of pick is shown in Figs. 288 and 289. This pick, which is made of cast steel throughout, is manufactured by Burys and Co., of Sheffield, and is known as the "interchangeable" pick. The merits claimed for this pick are, that being of solid cast steel, it will never require to be re-steeled, and will last longer than the ordinary pick; that as the helve is very endurable, and capable of being readily affixed to and removed from the head, one helve is sufficient for a number of tools; and that being thus interchangeable, when the pick requires to be re-sharpened, the helve need not be sent with the head to the fire, where it is liable to become shrunken from exposure to the heat. By sending only the head, not only does the helve escape damage, but the labour of carrying it is saved, and as one helve is sufficient for several picks, the labour of carrying helves is, under all circumstances, greatly lessened. To strengthen the helve, as well as to facilitate its easy application to the eye of the head, the feather is reduced, and a ferrule or hoop is affixed, as shown in the figure. By this means, the liability to wince is removed, or at least very materially diminished. The cost of these helves is 1*s.* 9*d.* each; that of the picks about 9*d.* per lb. for the lighter, and 8*d.* per lb. for the heavier kinds.

The pick commonly used in Cornwall, and in some other metal mining districts, is that shown in Figs. 290 and 291, and known as the poll-pick. It has one stem and one stump called the "poll." The face of the latter is steeled to form a pane, like a sledge, to render it suitable for striking blows. The pick is generally forged out of $1\frac{1}{8}$ inch iron, and weighs, without the helve, about 4 lbs. Sometimes the head is made quite straight. This tool is a favourite one with metal miners. Possessing the features of both the pick and the sledge, it may be used for the purposes for which those tools are intended. It is commonly used for driving in wedges, and not unfrequently it is employed as a wedge by striking it on the poll end. The pick shown in Fig. 290 is for use in hard ground; it has the following dimensions: Length of pick end, $12\frac{1}{2}$ inches; length of poll end, 3 inches; length of eye, 2·2 inches; width over eye, 3·1 inches; width of poll end, 1·2 inch; width of pick end, 1·1 inch; thickness, or depth, of poll end, 1·2 inch; thickness of pick end, 1·1 inch. The length of the helve is 26 inches; the point is set at an angle of 85° to the helve. Total weight, $8\frac{1}{2}$ lbs. The pick

shown in Fig. 291 is for use in soft ground. Its dimensions are: Length of pick end, 17·5 inches; length of poll end, 3 inches; length of eye, 2·1 inches; width over eye, 1 inch; width of poll end, 0·8 inch; width of pick end, 0·8 inch; thickness of poll end, 0·8 inch; thickness of pick end, 0·9 inch. The length of the helve, which is set at an angle of 83°, is $26\frac{1}{2}$ inches. The total weight is about 2 lbs. 10 oz.

Fig. 292 represents a "slitter" pick, used for slitting out mineral veins. It is double armed, one end being worked up to the point and the other to a horizontal cutting edge 0·4 inch wide. The head is 15·7 inches long, and the handle 29 inches. The weight of this tool is about 3 lbs. 10 oz.

Fig. 293 shows a Californian "drifting" or quartz pick. It is used chiefly in narrow drifts where there is not much room to swing the tool; and also in working out the "gauge" or "salvage" from quartz veins. A common size used weighs from $3\frac{1}{2}$ lbs. to 4 lbs., exclusive of the helve. A notable improvement of construction will be observed in the eye, which is "raised" or lengthened to give a large bearing surface to the helve, an important condition in picks that are used much for prizing.

Fig. 294 shows a "poll" pick from the same locality. This pick has the same form of eye as the preceding. A size most commonly used is about $16\frac{1}{2}$ inches long, and weighs about 5 lbs. The poll pick is a favourite tool among the miners, many of whom are Cornishmen, of the San Francisco district.

Wedges.—The wedge constitutes an important instrument in the hands of the miner. Large numbers of them are employed in every mine, as many as a dozen being sometimes required by one miner. They are used to break down large masses of hard coal, to force out blocks of rock by driving them into the joints, and to dislodge masses of rock that have been loosened by blasting. In jointed or vughy rock, they often do great service. Wedges are made of iron, and are steeled at the edge. In length, they vary from 6 inches to 18 inches; but a common size is 12 inches. Their thickness is generally about 1 inch, and their breadth $1\frac{3}{4}$ inch. These dimensions, however, are frequently varied slightly.

Fig. 295 represents a coal wedge used in South Wales. The penetrating side forms a slender rectangular pyramid; the striking side is of an irregular eight-sided section, tapered from the base of the wedge. In side elevation, the breadth diminishes uniformly from the striking face to the point. The length is $13\frac{1}{4}$ inches; in central section, the breadth is $1\frac{7}{8}$ inch, and the thickness $\frac{7}{8}$ inch. On the striking face, the breadth is $1\frac{1}{8}$ inch, and the thickness 1 inch. The weight of the wedge is 3 lbs. 14 oz.

Fig. 296 is a coal wedge used in North Wales. The tapering sides of this wedge are bounded by curved lines, instead of straight ones, as in the preceding example. The length is $11\frac{1}{2}$ inches, and in the greatest section, the breadth is $1\frac{3}{4}$ inch and the thickness $\frac{7}{8}$ inch. The weight of the wedge is 3 lbs. 9 oz.

Fig. 297 represents a wedge used in the north of England. The sides are straight, like those of South Wales. The length is 12 inches, and the greatest section, or base of the wedge, 6 inches distant from the point, is a rectangle, $2\frac{1}{4}$ inches broad by $\frac{7}{8}$ inch thick. The striking face is an irregular octagon, 1 inch broad by $\frac{3}{4}$ inch thick. The point is cut off to a rectangle $\frac{1}{8}$ inch in the side. The weight of the wedge is 4 lbs.

Fig. 298 is a stone wedge, from the same locality. The length is $6\frac{1}{2}$ inches; the wedge end is

$3\frac{1}{2}$ inches long, and is drawn in from a rectangular section $1\frac{1}{3}$ inch wide and $1\frac{1}{8}$ thick. The opposite end is drawn in by a tapering eight-sided section to a striking face $\frac{7}{8}$ inch in diameter. The weight of this wedge is 2 lbs. 1 oz.

A wedge terminating in a point instead of a chisel edge is called a "gad." Gads are much used in metal mining for working jointy or vughy ground, or rock which has been fissured by a blast. They are of various sizes; the common lengths are from 6 inches to 12 inches in length. Fig. 299 shows a Cornish gad. It is 6 inches in length, 0·9 inch tapered to 0·8 inch in breadth, and 0·6 inch in thickness; it has a central swell in breadth, but tapers uniformly in thickness from poll to point. The weight is about 10 oz.

Ore-dressing Hammers.—Besides the sledge, which has been already described, other hammers are used for breaking up ore. The "cobbing" hammer, used for dressing ores by hand, is shown in Figs. 300 to 302; in this the arms curve upward from the centre. In Fig. 300, the head is 13·1 inches long, and has an elliptical eye or socket 1·1 inch in length; the breadth across the eye, 1·6 inch. The striking faces are rectangular, being 1·7 inch deep by 0·6 broad; the depth at the centre is 1·3 inch. The arms taper in breadth from 0·8 inch at the centre to 0·6 inch at the faces. The helve is 9 inches in length; the total weight is about $4\frac{3}{4}$ lbs. Fig. 301 is a similar tool, of somewhat smaller dimensions. The arms are more strongly curved than those of the preceding hammer, the depth of the curve at the centre being 0·7 inch; they are of the same breadth throughout. The total weight is about $3\frac{1}{2}$ lbs. Fig. 302 is a still smaller tool, in which the arms are less curved than in the preceding ones. The length of the head is 8·1 inches; that of the eye is 0·9 inch; the breadth across the eye is 1·5 inch. The striking faces are 1·1 inch deep and 0·6 inch broad. The depth of the curve of the top surface is 0·3 inch; the total weight is about $2\frac{1}{4}$ lbs.

The "spalling" hammer, Fig. 303, is used for breaking up pieces of ore for sorting previous to stamping or crushing. The head is of the pointing pattern, but has hemispherical ends; it is almost identical in form with the common road-metalling hammer. The weight of the head varies from 2 lbs. to 3 lbs.; the length of the handle from 26 to 30 inches.

The "bucking iron," Fig. 304, is a tool that is also used for dressing ores by hand. It consists of a rectangular iron striking plate, having an eye or stirrup welded on to its upper surface to receive the helve. In the tool illustrated, the striking plate is 5 inches long by 4 inches broad, by $\frac{3}{4}$ inch thick. The eye, or stirrup, is $3\frac{1}{4}$ inches in height and 1 inch in breadth. The helve, which is wedged into the stirrup, is 16 inches long; and the weight of the tool complete is about 6 lbs.

The Kind-Chaudron Shaft-sinking Machinery.—Within the last few years a system of sinking shafts through water-bearing strata has been introduced and adopted on the continent of Europe and in England with marked success. This, which is known as the Kind-Chaudron system of excavating, consists in boring out the shaft from the surface by means of apparatus similar in character to that used for prospective borings. The machines and tools used are those of Kind modified and adapted by M. Chaudron, a Belgian engineer, who has added the moss box to form a water-tight joint at the base of the tubbing, which is put in after the water-bearing stratum has been passed through. The success which has hitherto attended the operations of these engineers, has brought their system gradually into favour; and the notable economy which it effects in difficult ground is likely to lead to its general adoption in such circumstances. It is, therefore, desirable to illustrate the machines and tools used somewhat fully, and to describe their construction and the mode of their application. Emerson Bainbridge gave in 1871, in a paper read by him before the Institution of Civil Engineers,

a detailed description of the Kind-Chaudron system, which paper will be found to be profusely illustrated by diagrams and sketches. The following is extracted from that paper :—

"The Kind-Chaudron system is divisible into five distinct processes, namely: The erection of the necessary machinery on the surface, and the opening of the mine; the boring of the pits to the lowest part of the water-bearing strata; the placing of the tubbing; the introduction of cement behind the tubbing to complete its solidity; the extraction of the water from the pits, and the placing of the wedging cribs, or 'faux cuvelage,' below the moss box.

"Figs. 305 to 307 show in elevations and in plan the plant usually employed on the surface. D is a small capstan engine, having a cylinder 20 inches in diameter and a stroke of 32 inches, working on the third motion. Attached to this engine, and working in the small pit C, is a counterbalance weight. This engine is used for raising and lowering boring tools, and for lifting the debris resulting from the boring. As far as the platform, which is about 10 feet from the surface, the pit has a diameter of 19 feet, or 4 feet more than the diameter of the pit below. At a level of about 38 feet above this platform, there is a tramway on which small waggons run, carrying the debris cylinder on one side, and the boring tools on the other. At a level of 48 feet above the platform are placed supports for the wooden spears, to which the boring tools are attached. The machinery for boring is worked by a cylinder, which has a diameter of $39\frac{1}{3}$ inches, and a full stroke of $39\frac{1}{3}$ inches, the usual stroke varying from 2 feet to 3 feet. A massive beam of wood transmits motion from this cylinder to the boring apparatus, the connection between the beam and the piston rod and the beam and the boring tools being made by a chain. The engine-man sits close to the engine, and applies the steam above the piston only. The down stroke of the boring tools is caused by the sudden opening of the exhaust, and a frame then prevents the shock of the boring rods from being too severe. The engines work at speeds varying from twelve to eighteen strokes a minute, according to the character of the strata passed through.

"After the working platform is fixed, the first boring tool applied is the small trepan, Figs. 308 to 311. This tool is attached to the wooden beam by the arrangement shown by Fig. 312. The boring tools can be lowered at pleasure by means of an adjusting screw, Figs. 313 and 314, which can be moved through a distance of 2 feet 6 inches. Next in order comes the handle for boring, Figs. 315 and 316. This is worked by four men on the platform, and is turned by the aid of a swivel. Attached to the handle-piece are wooden rods, made from Riga pitch pine. These rods, Figs. 317 and 318, are 59 feet in length, and $7\frac{3}{4}$ inches square. A swivelled ring, Figs. 319 and 320, is attached to the rope when raising and lowering the boring rods. The small trepan cuts a hole 4 feet $8\frac{3}{4}$ inches in diameter; and has fourteen teeth, fitted in cylindrical holes, and secured by pins entering through circular slots. The teeth are steeled. At a distance of 4 feet 4 inches above the main teeth of the trepan there is an arm, Fig. 311, with a tooth at each end. This piece answers the purpose of a guide, and, at the same time, removes irregularities from the sides of the hole. At a distance of 13 feet 6 inches above the main teeth are the actual guides, consisting of two strong arms of iron fixed on the tool, and placed at right angles to each other. The hole made by the small trepan is not kept at any fixed distance in advance of the full-sized pit, but the distance generally varies from 10 to 30 yards. With the small trepan, which weighs 8 tons, the progress varies from 6 to 10 feet a day.

"The large trepan, Figs. 321 to 323, weighs $16\frac{1}{2}$ tons, is forged in one solid piece, and has twenty-eight teeth. A projection of iron forms the centre of this trepan, and fits loosely into

the hole made by the small trepan, acting as a guide for the tool. At a distance of 7 feet 6 inches above the teeth, a guide is sometimes fixed on the frame, but is not furnished with teeth. At a distance of 13 feet 3 inches from the teeth are two other guides, at right angles to each other. These guides are let down the pit with the boring tool, the hinged part of the guides being raised whilst passing through the beams at the top of the pit, which are only 6 feet 7 inches apart. When the tool is ready to work, the two arms are let down against the side of the pit, and are hung in the shaft by ropes, thus acting as a guide for the trepan, which moves through them. To provide against a shock to the spears when the trepan strikes the rock at the down stroke, at the upper part of the frame a slot motion is arranged, the play of which amounts to about $\frac{1}{2}$ inch. The teeth of the large trepan are not horizontal, but are deeper towards the inside of the pit, the face of the inside tooth being $3\frac{3}{4}$ inches lower than the outside. The object of this is to cause the debris to drop at once into the small hole, by the face of the rock at the bottom of the pit being somewhat inclined. The teeth used are the same both for the large and the small trepan, and weigh about 72 lbs. each. As a rule, only one set of teeth is kept in use, this set working for twelve hours, the alternate twelve hours being employed in raising the debris. This time is divided in about the following proportions: Boring, twelve hours; drawing the rods, one hour to five hours, according to depth; raising the debris, two hours; and lowering the rods, one hour to five hours. The maximum speed of the larger trepan may be taken at about 3 feet a day. The ordinary distance sunk is not more than 2 feet a day; and in flint and other hard rocks, the boring has proceeded as slowly as 3 inches a day.

"The debris in the small bore-hole contains pieces of a maximum size of about 8 cubic inches. In the large boring, pieces of rock measuring 32 cubic inches have been found. As a rule, however, the material is beaten very fine, having much the appearance of mud or sand. In both the large and the small borings, the debris is raised by a sludger or spoon, Figs. 324 to 326, consisting of a wrought-iron cylinder, 3 feet 3 inches in diameter, by 6 feet 9 inches long, and containing two flap valves at the bottom, through which the excavated material enters. This apparatus is passed down the shaft by the bore rods, and it is moved up and down through a distance varying from 6 to 8 inches, for about a quarter of an hour, and is then drawn up and emptied. In some cases where the rock is hard, three sizes of trepan are used consecutively, the sizes being—5 feet, 8 feet, and 13 feet. Some other tools and appliances used during the boring operations, including the key used at the surface to disconnect the rods, are shown on the accompanying plates.

"Should broken tools fall into the shaft, several varieties of apparatus are used for their recovery. In case of broken rods of any kind having a protuberance that can be clutched, the crow already described enables the object to be taken hold of very readily. Where the broken part has no shoulder which can be held, but is simply a bar, the apparatus shown in Figs. 327 and 328 is employed. This is composed of two parts. The rods M M, the bottom of which have teeth inside, are prevented from diverging by the cone and slide on the main rods. When passed over a rod or pipe, they clutch it by means of the teeth, and draw it up. M. Chaudron has, by this tool, raised a column of pipes 295 feet in length and 8 inches in diameter. An instrument, called a 'grapin,' Figs. 329 and 330, is used for raising broken teeth or other small objects which may have fallen into the bottom of the shaft. This tool also has one part sliding in the other, and is lowered with the claws closed. The parts B B are moved by two ropes worked from the surface. By weighting the bar A A, which is attached to the moving parts, the pressure desired can be exerted on the claws C C. The weight is

then lifted, the claws are opened, and are made to close upon the substance to be raised. This instrument is now seldom required.

"In boring shafts in the manner described, without being able to prove in the usual way the perpendicularity of the shaft, it might be feared that the system would be open to objection on this account. It appears, however, that in all cases where M. Chaudron has sunk shafts by this system he has succeeded in making them perfectly vertical. This is ensured by the effect of the treble guide, which the chisels and the two sets of arms attached to the boring tools afford, and by the fact that if the least divergence from a plumb line is made by the boring tool, the friction of the tool upon one side of the shaft is so great as to cause the borers to be unable to turn the instrument.

"By boring alternately with the large and the small instrument, the shaft is at length sunk to the point at which the lowest feeder of water is encountered. In a new district, this has to be taken, to some extent, at hazard; but where pits have been sunk previously, it is not difficult to tell, by observing the strata, almost the exact point at which the bottom of the tubbing may be safely fixed. This point being ascertained, the third process is arrived at.

"As the object of placing tubbing in a shaft is effectually to shut off the feeders, and to secure a water-tight joint at the base, it is important that the bed on which the moss box has to rest should be quite level and smooth. This is attained by the use of a tool termed a 'scraper,' attached to the bore rods, the blades being made to move round the face of the bed intended for the moss box. The tubbing employed is cast in complete cylinders of the diameter required, one of about 4 feet 9 inches high. Each ring has an inside flange at the top and bottom, and also a rib in the middle, the top and bottom of the ring being turned and faced. The rings of tubbing are attached to each other by twenty-eight bolts 1·1 inch in diameter, passed through holes bored in the flanges. The tubbing is suspended in the pit by means of six rods, which are let down by capstans placed at a distance of 30 feet above the top of the pit. These machines work upon long screws. When a new ring of tubbing is added, the rods are detached at a lower level, and are hung upon chains, thus leaving an open space for passing it forward. Before each ring is put into the pit it is tested by hydraulic apparatus. The tubbing is usually proved to one-half more pressure than it is expected to be subjected to.

"The joints between the rings of tubbing are made with sheet lead $\frac{1}{8}$ of an inch thick, coated with red-lead. The lead is allowed to obtrude from the joint $\frac{1}{3}$ of an inch, and is wedged up by a tool which has a face $\frac{1}{12}$ of an inch thick. The mode of suspending the tubbing to the rods will be understood by referring to Figs. 331 and 332. The rods are attached to a ring by the bolts connecting one ring of tubbing with another. The bottom ring of tubbing and the ring carrying the moss box have their top flange turned inwards, but their bottom flange outwards. A strong web of iron, forming the base of a tube $16\frac{1}{2}$ inches in diameter, is attached to the tubbing. The object of this tube is to cause the water in the shaft to ease the suspension rods, by bearing part of the weight of the tubbing. Cocks to admit water are placed at intervals up the tube, by which means the weight upon the rods can be easily regulated so that not more than one-tenth to one-twentieth of the weight of the tubbing is suspended by the rods at one time. The ring holding the moss box is hung from the bottom joint in the tubbing by sliding rods.

"The arrangement of the moss box, which forms the base of the tubbing, is one of the most important points requiring attention in this system of sinking. Ordinary peat moss is used. It is enclosed in a net, which, with the aid of springs, keeps it in its place during the descent of the

tubbing. When the moss box, which hangs on short rods fixed to the tubbing, reaches the face of rock, it is dropped gently upon it, and the whole weight of the tubbing is allowed to rest upon the bed. This compresses the moss, the capacity of the chamber holding it is diminished, and the moss is forced against the sides of the shaft, thus forming a water-tight joint, past which no water can escape. This completes the third process.

"It may be noted that up to this point the following important differences between this and the ordinary system of placing tubbing are to be observed:—The tubbing, on reaching its bed, bears the aggregate pressure of all the feeders of water which have been met with in the shaft. The tubbing, having been passed down the shaft in the manner described, no wedging behind, or other modes of consolidating it in the shaft, have been carried out. The connection between each ring of tubbing is so carefully made, that the repeated wedging of the joints, as in the ordinary system, is rendered unnecessary. The pit is still full of water up to the ordinary level.

"Under these conditions the next process is:—The introduction of cement behind the tubbing to complete its solidity.

"Before the water is removed, the annular space between the tubbing and the sides of the shaft is filled with hydraulic cement, to render the tubbing impermeable, by a process of consolidation, less liable to the effect of any pressure of water, or gas, which may be exerted towards the centre of the shaft. The cement is inserted behind the tubing by close ladles, Figs. 333 and 334, capable of holding 44 gallons, and consisting of two iron plates, $\frac{1}{8}$ of an inch thick, fixed on two wooden uprights $3\frac{1}{8}$ inches square. This apparatus is curved to suit the mean circumference of the space to be concreted. A piston is placed at the top of the ladle, and to this piston is attached a rod, which can be moved from the surface; a door is also attached to the piston. The ladle containing the concrete is passed down behind the tubbing by means of a windlass at the surface, and when it reaches the lowest point, the piston is pushed down and the cement allowed to escape from the chamber. The weight of the cement and the ladle is sufficient with a little ballast to enable it to descend easily.

"A number of experiments have been made to discover a cement which will not harden too quickly, and which, when hardened, will form a perfectly compact and solid mass. A composition having the following proportions, has been found the best:—Hydraulic lime, from the lias near Metz, slacked by sprinkling, 1 part. Picked sand, from the Vosges sandstone, 1 part. Trass, from Andernacht on the Rhine, 1 part. Cement, from Ropp (Haute Sâone), $\frac{1}{4}$ part.

"Six men are employed in putting in the cement:—two at the windlass for letting down the ladle, two for working the rods attached to the piston, and two on the working platform. The rods referred to have been found such an inconvenience, that lately a rope on another windlass has been used, and an appliance arranged for dropping the piston by moving the rope.

"When a sufficient time has elapsed for the cement to harden, the water within the tubbing, now effectually separated from the feeders, is drawn out by a bucket worked by the crab engine,—an operation which occupies from one to three weeks, according to circumstances. When concluded, the joint between the moss box and the rock bed can be examined. In some cases this joint is considered sufficient; but it is generally thought desirable to form a base to the tubbing, by building a few feet of brickwork in cement on a ring or crib of wood. Another wooden crib is then placed on the top of this brickwork, and above this, two cast-iron segmental wedging cribs with a broad bed also wedged perfectly tight. On the base so prepared, four or more rings of tubbing in segments

are fixed, the top ring coming close against the bottom of the moss box. This being done, the work is completed, and the sinking of the shaft is continued in the ordinary way.

TABLE showing the DURATION and COST of EIGHT different CONTINENTAL SINKINGS made by the KIND-CHAUDRON process.

						Time.		Cost.						
Locality.	Name of Colliery.	Year in which Sinking was commenced.	Diameter of Pit when Finished.	Depth of Pit to bottom of Water-bearing Strata.	Total Length of Tubbing in the Shaft.	Duration of Sinking to the date of the completion of Tubbing.	Average Rate at which Sinking progressed.	Surface Plant.	Boring.	Tubbing.	Concrete Work.	Wedgiog Cribs at Bottom, &c.	Total.	Complete Cost per Foot to bottom of Water-bearing Strata in each Pit.
			feet.	feet.	feet.	months.	feet per month.	£	£	£	£	£	£	£
Belgium ..	St. Waast	1853	11·90	321	219	26	12·4	1,216	2,048	5,110	Comprised in Cost of 'Tubbing'		8,374	26
	St. Marie	1859	5·97	344	202	14	24·5	640	750	1,188			2,578	7
	St. Barbe	1862	11·97	295	177	19	15·5	2,916	940	1,224	..	938	6,018	20
France	L'Hôpital, 1 ..	1865	5·90	521	472	43	12·1	1,988	3,720	3,180	472	246	9,606	18
	" 2 ..	1865	11·15	523	469	39	13·4	2,636	5,670	6,768	600	400	16,074	30
Westphalia ..	Rothuasen, 1 ..	1866	6·23	331	221	14	23·6	1,852	1,496	2,752	408	280	6,788	20
	" 2 ..	1866	11·97	341	334	25	13·6	3,186	3,068	5,700	574	600	13,128	38
France	L'Escarpelle, 1 ..	1867	10·49	354	332	11	32·2	1,608	1,108	3,612	363	310	7,001	20
	" 2 ..	1867	7·21	..	..	..	..	Now being prosecuted.						
Belgium ..	Maurage	1869	11·97	656	541	..	..							

"On an average of ten sinkings, by the method practised in England, the speed of sinking was found by the writer of the paper to be 8·8 feet per month, and the cost £114·6 per foot; whilst with the Chaudron system the average of eight sinkings showed a cost of £22·4 per foot, the progress made per month amounting to 18·1 feet. This striking result illustrates the great importance which the Kind-Chaudron mode of dealing with water-bearing strata is likely to have. This comparison cannot be considered to apply with all its force to English mining, since, as a rule, the sinkings abroad encounter a much greater quantity of water and pass through softer rocks than in England. At the same time it must be expected that in the future, sinkings of a character more closely allied to those in Belgium and Germany will have to be carried out.

"Reference has hitherto only been made to the application of the Chaudron system to shafts in which the water has to be tubbed back. There are, however, other conditions to which the system will probably be economically applicable. Pits are frequently sunk at the dip of a coalfield, through large feeders of water, and in one of so shallow a depth as from 100 yards to 200 yards, the application of tubbing would be useless. In this case, instead of using expensive pumping machinery, which is liable to accident, and impedes the progress of sinking, cost might be saved, if this system of boring were adopted, and pumping machinery applied after the coal was reached.

"To arrive at the relative economy in such a case as this, M. Chaudron has given an estimate for two pits which had been sunk a depth of 120 yards under the superintendence of the writer. M. Chaudron's estimate, inclusive of royalty, is about 33 per cent. less than the actual cost of these pits.

"There are conditions in the sinking of shafts through aqueous strata under which it may be found more economical to use the old system, such conditions being:—1. Where the feeders met with are separated by compact beds of rock, on which wedging cribs can be laid. 2. Where the feeders are not very large, yielding, say, 800 gallons per minute, and where they can be contended with by engines intended as future winding engines.

"The simplicity of the Kind-Chaudron process affords but little scope for the occurrence of

accidents. The regularity with which the boring is conducted, the appliances in use for the safe and dexterous handling of the tools, the care with which the tubbing is placed in the shaft and made solid, and the general appearance which the works present of a minimum of moving plant, are all points which conduce to this result.

"In conclusion, the advantages which the Kind-Chaudron system of sinking shafts appears to possess may be stated as follows:—1. A considerable saving in the actual expenditure on the sinkings is effected. 2. The expenditure of capital is lessened by the quick progress made through the water-bearing strata. 3. The abolition of all pumping machinery, and, as a consequence, the avoidance of accidents, so frequent and costly in sinkings where large and extensive pumping machinery is employed. 4. The saving of the heavy cost consequent upon the wear and tear of a large quantity of moving stock as used in pits sunk by means of pumps. 5. The sinkers work on a dry stage and not in water; they are thus enabled to work a much longer shift, and to apply their labour in a far more effectual manner. Their work furthermore is of such a character as to require less wages than are demanded by the practical sinkers, who would have to be engaged for the ordinary process. 6. The avoidance, by the use of solid rings, of the liability to leakage and breaking in of the tubbing, which occur with the vertical seams of the segmentary tubbing usually employed. 7. The pressure of water in the pit during the sinking prevents in a marked degree the sand or other loose strata from coming into the shaft during the sinking. 8. As compared with sinkings where extensive pumping machinery is employed, the saving of fuel, which in new districts where the cost of coal is heavy, is an important item.

"It may be observed that as sinkings for coal in this country become deeper, and as they will necessarily encounter more water than heretofore, the cost of the shafts will form a larger proportion than at present of the total cost of opening out a colliery. Hence any system which appears to promise saving of labour, economy of time, and a greater degree of permanent security, than the old system of sinking and placing the tubbing, merits the serious consideration of all mining engineers."

The Kind-Chaudron system of sinking through water-bearing strata, which, it will be observed, is extremely ingenious, has thus been proved by experience to be eminently practical. Provided care be taken in the performance of all the operations, but more especially in that of fixing the moss box, success can certainly be attained in water-bearing strata of not too weak a character. In ground, however, that will not stand, the difficulties would be greater, and, in such a case, it might be necessary to have recourse to a system of tubing similar to that adopted in ordinary bore holes. It should be borne in mind, notwithstanding, that as the excavation is kept full of water, the tendency of the ground to run is, as remarked above, greatly less than when the sinking is carried on by the ordinary means. There can be little doubt that, with modifications of detail to suit the requirements of particular cases, the system can be made applicable to the most difficult ground; and as it is independent of the quantity of water met with, it offers advantages which no other system possesses, or can be made to possess. Triger's and Guibal's systems, by both of which the sinking is carried on without clearing the shaft of water, have peculiar merits that render them very effective in certain difficult circumstances; but the Kind-Chaudron system is of more general application, and for that reason it may be predicted of it that eventually it will entirely supersede the former, and be commonly adopted in England, as it already has been upon the Continent.

Coal-cutting Machines.—The substitution of machines for hand labour in the hewing of coal is, notwithstanding the only partial success which has hitherto been attained, one of the most important advances that have been made of late years. The labour of hewing coal by hand is of a very severe character. The necessity for undercutting to a great depth in a narrow groove, and the constrained attitude of the hewer, especially in thin seams, combine to render his occupation the most laborious of any connected with coal getting. It is also evident that the force of the hewer, exerted under such unfavourable conditions, must be very wastefully applied, and, therefore, is not employed according to the requirements of economical production. Besides this, even the proportion of the force which is made effective is improperly utilized, since it is made productive of a large quantity of small coal. When holing to the usual depth of 3 feet, the average height of the cut, even with skilful hewing, is not less than 9 inches, and when it is necessary to hole in the seams such an excavation destroys an important proportion of the coal. Hence it becomes desirable to substitute machine for hand labour, a substitution that will obviate these numerous and great disadvantages, and import into the operations of coal getting other advantages than those possessed by hand labour. Another important circumstance is the altered relation of capital and labour. To lessen the dependence of production upon hand labour, it is highly desirable that machinery should be applied to the undercutting of coal seams. Moreover, the same change is called for by the constantly and rapidly increasing demand, with which it will be impossible long to keep pace by the means hitherto employed.

It would seem to be a comparatively easy matter to design and construct machinery capable of performing the work of undercutting the seams effectively. Experience has, however, shown that the difficulties are greater than they appear. Numerous attempts have been made to overcome them, and numerous failures have been recorded. Some of these attempts have resulted in the attainment of a certain degree of success, and it is to the improvement of the machines which are constructed on the principles involved in these attempts that we look for a satisfactory solution of the problem. Without entering into a discussion concerning these principles, we shall merely give a detailed description of those machines which have shown good results in continued practice. These machines may be regarded as fair representatives of the types that have hitherto been introduced.

Winstanley and Barker's Coal Machine.—This machine, illustrated in Figs. 333 to 340, like most other coal cutters, is driven by compressed air, which is conveyed down the pit shaft and along the main roads and drawing roads in iron pipes, and from the end of the drawing road to the machine in an indiarubber hose-pipe of 2 inches diameter.

The frame of the machine is about 6 feet in length, and is supported on flanged wheels, which run on the ordinary tramway of the mine; the gauge in this instance is 2 feet, but it can be varied to suit other gauges, as may be required. On the front part of the frame are two oscillating cylinders, of 9 inches diameter and 6 inches stroke, provided with ordinary slide valves. The piston rods are connected to an upright crank-shaft, on the bottom end of which is a driving pinion, shrouded at the top, and having only five teeth, as shown in the plan.

The teeth of this pinion gear into the teeth of a spur-wheel, which is also the cutting wheel, and is 3 feet 6 inches diameter; the driving power is thus applied with the greatest mechanical advantage, that is, directly on the circumference of the cutting wheel.

The cutters are fixed in the circumference of the wheel, one in every cog or tooth, their points

projecting 1 inch beyond the teeth. The mode of fixing them is shown in the drawings, as well as the three patterns of cutter, which are arranged successively round the cutting wheel.

The cutting wheel revolves at the end of an arm consisting of a broad flat plate, at the opposite extremity of which is a toothed segment or quadrant, actuated by a worm and hand-wheel, whereby the arm carrying the cutting wheel can be turned partly round in its bearing in the frame of the machine. Before the machine commences to hole in the coal, the cutting wheel is under the back part of the frame, as shown dotted in the plan, almost touching the straight face of the coal; and on starting the engines, the attendant, by turning the hand-wheel and worm, causes the cutting wheel gradually to hole its way into the coal, until the arm is at right angles with the frame of the machine, as shown in the plan and the transverse action. In this position, the cutter is holing about 3 feet in depth from the face of the coal; and it can be placed in any position to hole less than this depth if required.

As soon as the cutter has worked into the coal to the full depth, the machine is drawn along the face of the coal as it holes or cuts its way, throwing out the small coal or slack between the tram rails upon which the machine runs. The thickness of the holing or groove cut out is 3 inches; this thickness, however, can be reduced, if desired, by the use of a thinner cutting wheel. There is no traverse motion on the machine, as it is considered simpler to draw it along the face by means of a small crab, turned by a lad at the end of the working face. When the holing of the entire length of the face is completed, the cutting wheel is brought back to its original position underneath the frame of the machine, by means of the worm and hand-wheel, and is ready for beginning to hole at the commencement of the new face as soon as the coal already holed has been removed.

The chief advantages in this machine are, that the swivelling movement of the arm carrying the cutter enables it to cut or hole its own way into the coal, the depth of cut increasing from nothing to about 3 feet; and by the same movement the cutter is brought back underneath the frame of the machine when not at work. It will also be perceived that when the cutter is in this position, drawn back underneath the frame, it can be taken through any narrow roads or parts of the mine, without the necessity of removing the cutter from the machine, the space required for the machine to pass being only the width or diameter of the cutting wheel, which with the cutters is 3 feet 8 inches. Again, were it not for this arrangement, a portion of the coal would have to be cut out by hand labour, for the purpose of inserting the cutting wheel, unless the machine were started at the corner of a pillar, or what is called a "loose end."

An important advantage in this machine is, that the power to drive the cutting wheel is applied direct on the circumference of the wheel; this mode of gearing also allows the small pieces of coal or slack to fall through to the bottom, so as not to lock or clog up the teeth of the machine.

In reference to one of these machines at work at the Platt Lane Colliery, Wigan, Mr. R. F. Martin, in an admirable paper contributed by him to the Proceedings of the Chesterfield and Derbyshire Institute of Mining Engineers, makes the following remarks, which point to certain improvements of construction that deserve consideration :—

"The great feature of this machine is the thorough adaptation of the parts to the work to be done. The two cylinders driving one crank in a horizontal plane, and the star-wheel on the lower end of the crank-shaft gearing directly into the teeth of the cutter, constitute the simplest form of coal cutter which can be imagined. Moreover, the rotation of the centre of the cutter round the

axis of the crank-shaft, so as to enable it to start its own cut anywhere, is a feature of the highest importance. The only theoretical improvement which can be suggested is the addition of a *self-acting feed* to the gear; and this will no doubt be soon done. There are, however, several details in which the machine might be improved.

"1. The cutter and cutter frame appear to be unnecessarily heavy, and it is thought that the use of *cast steel* for these parts might make them both lighter and more handy.

"2. It should by all means be made to run on the ordinary gauge of the pit.

"3. The speed of the pistons is in reality very low. It will be possible to increase this, and thus decrease the amount of feed per revolution, or increase the cutting speed, as may be found advisable."

The writer makes frequent comparison of the Winstanley machine with the Baird and the Gillot machines, which he describes in the following sections. These coal cutters, with their auxiliary appliances and requisite fittings, are described as applied to work, the former at the Elemore Colliery, Durham, and the latter at the Wharncliffe Silkstone Collieries, near Barnsley, Yorkshire.

Baird's Coal-cutting Machine.—This machine is driven by compressed air. The air is compressed by the winding engine of the upcast pit, which is now no longer drawing coal. The air-cylinder is 24 inches in diameter and 24 inches stroke. It compresses to 45 lbs. per square inch, and works twenty-four strokes per minute.

The air is compressed into a boiler, with a safety valve loaded to 45 lbs., and is taken down the shaft in 6-inch cast-iron pipes. The same pipes are continued, mostly along the floor of the main waggon way, where they would appear to be somewhat liable to accidents, for about 1000 yards underground, when they are reduced to 3 inches, and finally to 2 inches of flexible tubing, which supplies one single coal-cutting machine. There is, of course, a certain amount of leakage in the joints, and from numerous observations, the results of which were shown to the author, it appeared that the difference between pressure in the reservoir at bank, and that at the machine when working, was 2 lbs. per square inch. The pipes were nearly cold at the machine.

The face on which the machine is working is in the main coal, which at that point is nearly 5 feet thick, and is a splendid seam, with a strong freestone roof. There are about 120 yards of face, divided into six sections by gate roads in the solid, and the coal is being "brought back."

The machine, Figs. 341 to 343, has one air-cylinder A, $8\frac{1}{2}$ inches diameter by 12 inches stroke, which propels the machine and also drives the cutters.

The engine runs at about 240 revolutions per minute; but this speed is, as will be observed, considerably reduced by the gearing of the machine, and the cutters themselves appear to move very quietly.

The machine is exceedingly compact, and the parts are fairly easy of access; it is covered by a sheet-iron case when at work, to shield the gear from injury, and also to facilitate the moving forward of the rails and sleepers on which the machine runs.

It will be observed from the drawings that the gauge of the road is 2 feet 9 inches, which is far broader than the regular gauge of the pit. It is thus necessary to provide a special road, on which the machine runs. This is formed of short pit-rails R R, in 4 feet lengths, fitting into cast-iron sleepers, S S.

In consequence of the shortness of the lengths of rails, all the sleepers are joint-sleepers, and the

rails and sleepers are regularly taken up behind the machine and passed forward, along the sheet-iron cover before mentioned, to the man in front, who lays them down in readiness.

It will be observed in the drawings that the pressure upon the rails, due to the direction of the cut in the chisel faces, tends to draw them *towards* the coal face. This is clearly the right direction for the pressure, as it is very easy to set wooden chocks and wedges against the sleeper ends, when necessary, to prevent them from being drawn too near the face itself, while it would not be so easy to wedge the road up against the packs and props in the goaf.

The coal cutter is very heavy, weighing in all 25 cwt. The propelling gear is open to criticism, inasmuch as it was necessary to stop the machine every 3 yards in order to take a fresh hold of the chain. This objection of course could be easily got over in many ways. The plan pursued at Elemore was as follows: A fixed chain with long links was anchored back at the end of the "run" of the coal cutter, the end of the hauling chain was hooked into a link of this main chain, and was shifted forward from time to time.

There was also only one speed at which the coal cutter could be propelled, there being no arrangement in the hauling gear for "altering the feed." If the speed of propulsion proved too quick, the effect was usually to *stop the machine*. It would be easy to alter the arm G, which is worked by the eccentric E, so as to make a "variable feed:" and also to work the hauling barrel H by a friction clutch, so that it may slip if the cutters come across something unusually hard.

The shape of the cutting edges of the teeth is shown in the drawings. It is, no doubt, the result of a series of experiments, but the angle of the cutting edge would appear to be too great for obtaining the best results. With regard to the work done by the coal cutter, the average speed of progress of the machine is 1 foot per minute, 3 feet under. When the author was present, a distance of 3 yards was cut, 2 feet 3 inches under, in nine minutes. It did not, however, often happen that the distance cut exceeded 40 feet in the hour, including stoppages; the whole distance of 120 yards being, nevertheless, traversed with ease in the night's work. Three hands were employed at the machine, two men and a boy.

The holing was evidently very hard, though it was difficult to arrive at any comparison with our own seams by means of prices paid or work done, on account of the difference in the system of working. The coal cutter worked in the seam itself, and about 4 inches from the bottom, so that "round coal" was made from the small piece of the seam left below. The author has not been able to ascertain any instance of this machine cutting a long distance under, say for 5 feet or upwards.

The general design of this machine is strong and solid, and it is in many ways the right sort of tool for the rough usage of the pit. The working parts are also easy of access. On the other hand, its weight, 25 cwt., is very great. The single cylinder, of considerable size, is obviously not so advantageous as the double cylinders of the other cutters, although the machine would appear to give no trouble from this cause. The gearing between the cylinder and the vertical cutter-shaft, which is about $4\frac{1}{2}$ to 1, adds much to the friction and the liability to accident; and might, it is thought, be avoided. It is a question whether even the vertical shaft of the Winstanley machine might not be adopted with advantage, and so the bevelled wheels might be dispensed with. The gauge of the wheels of the machine does not fit the gauge of the pit, and thus a special road has to be employed. This should be avoided where possible. The adoption of a self-acting "feed," which appears to work successfully, is a great advantage; but, as has been before pointed out, the amount of feed should be capable of easy adjustment; the barrel ought to be so arranged that it can slip if the cutter jams;

and it should not be necessary to stop the machine in order to take up a fresh length of chain. It is a great drawback to this coal cutter that it is obliged to be started from a "loose-end," and cannot be entered anywhere, like the Winstanley cutter. The endless chain form of cutter offers great advantages in working over a very uneven floor; and by keeping a spare chain, with the cutters ready fixed, some time may be saved when it is necessary to shift them; but the form of the cutting teeth would not appear to be the best that could be devised to *cut*, not *scrape* the coal. The method of attaching the cutter, by means of bolts, is cumbrous, and capable of much improvement.

Gillot and Copley's Coal-cutting Machine.—The general construction of this machine will be seen from Figs. 344 and 345.

Two horizontal steeple-engines, with cylinders, A A, 7 inches in diameter and 12 inches stroke, drive a horizontal crank-shaft, B, carrying on either end a bevelled pinion, C; this gears into an inclined bevelled wheel, D, and another bevelled pinion, E, on the end of this intermediate shaft, drives the circular cutter.

The circular cutter F is *fixed* in position, not capable of rotation as in Winstanley's machine. It is made of cast steel, and very thin.

The cogs, by which it is driven, are formed by slotting out holes right through the substance of the cutter, and thus making what may be termed a lantern "crown-wheel."

In the periphery are fixed twenty steel teeth by means of set-bolts, the teeth being alternately *single* and *double.*

The flexible pipe, for the supply of compressed air, can be fixed on to either end of the machine, as there is a sort of "stand-pipe," H, fixed on to the top for this purpose. The cutter itself will fix on to either side of the frame, the gear being made reversible for this, so that the machine can be made to cut either right or left-handed.

It has no propelling gear, but is made to traverse by a chain and a winch at the far end of the face, worked by a boy.

The machine is employed to "hole" in the "Parkgate" seam, which contains 6 inches of clod in the middle of the coal; there being 2 feet 3 inches of coal below it, and 3 feet of good coal above it. The inclination of the seam is from 2 inches to $2\frac{1}{2}$ inches per yard. It requires two men to tend the machine, and a boy to haul at the winch.

The air-compressing engine has one cylinder 18 inches in diameter by 4 feet stroke, and works at 35 lbs. pressure fifty strokes per minute. The air-cylinder is 16 inches in diameter, 4 feet stroke, and pumps into an old boiler as receiver. The pipes are 4 inches in diameter for the first 400 yards, after that 2-inch gaspipe.

The coal cutter makes ninety strokes per minute. It would appear to take the whole power of the main engine to drive one coal-cutting machine at ninety strokes per minute.

The general results are as follows:—

The coal cutter has cut 26 yards, 3 feet 2 inches deep, in the clod, in fifty-seven minutes; and again 25 yards, 3 feet 2 inches deep, in forty-three minutes: so that, with fair working, 30 yards per hour may be reckoned on. The wages in these experiments came to $1\frac{3}{4}d.$ per yard cut, including the time spent in preparing, &c., and also engine-man's wages at the air-compressor, but not time in laying the road for the machine. It is found that this seam worked on the end with the machine will turn out *ten tons* of coal to *eight tons* by hand labour. This saving alone is, therefore, 25 per cent. on the coal. There is also the saving of $1\frac{3}{4}d.$ against $7d.$, or $5\frac{1}{4}d.$ per yard in the cost of holing.

The clod in the Parkgate seam is evidently very soft. The machine has been tried in the hard coal itself, and, though it was effectually cut, the work was not done so quickly as in the clod.

The framing of this machine might be improved; at present it is very light, and does not present sufficient rigidity. The use of a double engine is doubtless correct; but a horizontal steeple-engine—a form seldom if ever met with elsewhere—is neither so light, so compact, nor so strong, as are several other forms. The light steel cutter-wheel with the lantern-teeth on the face is decidedly a good feature, perhaps the best feature of the machine. Even here, however, there are two points in which Winstanley's cutter-wheel is an improvement.

1. The external cogs of the latter would enable a larger proportion of the wheel to be in the cut, so that a smaller wheel would be necessary to cut "3 feet under," than with the former machine.

2. The larger size of the spindle on which it rotates will give the cutter-wheel greater rigidity in the latter case than in the former. In other respects, the former cutter-wheel has the advantage.

The attachment of the cutter and frame to the machine by means of bolts is open to grave objections; this it, of course, shares with the Baird machine. The machine itself can be reversed with great ease, so as to cut either right or left-handed. In this respect it has a great advantage over both the Winstanley and the Baird cutters. The details of the machine might be much improved. The bearing surfaces might, with advantage, be made larger; and the necessary weight should be so distributed that the reciprocating parts may be as light as possible. There is no self-acting "feed," and, as before mentioned, this should be made an essential part of all such machines. The effective pressure of air at the machine, 35 lbs., would appear to be too low; the addition of 10 lbs. here, as in the Baird machine at Hetton, would make a great improvement. The cutter should, by all means, be so arranged as to start its own cut. This would hardly appear to be possible with the "Gillot" form of gear.

Besides the foregoing machines, the following claim attention :—

I.—A coal cutter at Platt Lane Colliery, manufactured by Ommany and Tatham, which is designed as an improvement upon Winstanley's machine. It has a long frame, and a horizontal air-cylinder, 6 inches diameter and 9 inches stroke, at each end. The pistons drive two cranks upon a horizontal crank-shaft placed midway between the cylinders. At the end of this crank-shaft is a bevelled wheel, which drives a vertical shaft, on the bottom of which is the usual star-pinion of Winstanley's machine. A good account of this machine was given by the men who worked it, but the author was not able to obtain any accurate results of its performances. It would appear to be an objection in it that the bevelled wheel on the top of the vertical shaft is the first point which strikes the coal when the machine is put too near the face; in fact, this wheel will prevent its being approached so near to the face as might otherwise be done. There is no self-acting hauling gear to this machine.

II.—A coal cutter, by "Heard," at Wharncliffe Silkstone pit, which, in many respects, resembles the machine of Messrs. Baird. A pair of air-cylinders, set at right angles to each other, drives one crank on the top of a vertical shaft. On the bottom of this shaft a "star-wheel" is keyed, and this actuates an endless chain furnished with teeth in the same sort of way as in the Baird's cutter. They, however, differ widely from the latter, being in form very like those in the Gillot and Copley machine. A third air-cylinder actuates a pair of small horizontal wheels, which press against one of the rails on which the machine runs. It thus propels itself in a similar

manner to Mr. Fell's centre-rail engines. This cutter does not appear to have been a success, chiefly because the work was neither as strong nor as simple as colliery work should be. Also the attempt to propel the machine by pressure on the rail resulted in thrusting the road out of shape, as well as advancing the cutters.

The Economic Coal-cutting Machine.—This coal cutter is shown in Figs. 344 to 349. It is thus described by the inventors:—

"For the purpose of undercutting the coal, a round cutter-bar is employed, having a spiral groove or thread in the form of a screw running from end to end. In the raised parts of the bar left after the groove is cut, are fixed, at regular intervals round the periphery, a number of suitable cutters projecting above the surface of the bar, and firmly fixed in longitudinal slots or grooves in the same by wedges or screws. These cutters are so arranged in the bar as to form a continuous line of cutters always presented to the surface of the coal or other mineral to be cut, the dust and cuttings from which fall into the spiral groove or thread cut in the bar, and, by the rotation of this latter, are drawn away from the cutters, leaving them clean and not liable to clog. To further assist the dust being drawn away, a semicircular shield or casing is fixed behind the cutter bar and extending its full length; this shield is carried with the bar, but is so arranged as to remain stationary while the bar rotates.

"The cutter-bar may be in one with, or connected to, a crank-shaft supported in suitable bearings. On the crank-shaft are discs acting in place of a fly-wheel. The whole of the bearings carrying the cutter bar and shaft are fixed on a circular frame, on which is mounted one or more cylinders, capable of rotating the aforesaid cutter bar by means of the usual pistons and connecting rods, the pistons being actuated in the before-mentioned cylinder or cylinders by steam, air, or other motive fluid.

"The circular frame carrying the cutter bar, cylinder, and connections, is in turn carried within another frame or trolly mounted on tram wheels, arranged for running on rails. The circular inner frame carrying the cutter bar, cylinder, and connections, is so made as to be capable of being canted to a position other than horizontal, irrespective of the outer frame or trolly, and of being turned round in a circle after the manner of a turntable, by means of a hand-wheel and worm fixed on the main carrying frame or trolly gearing into a suitable wheel, or into teeth attached to the inner frame carrying the cutter bar.

"The cutter bar is so made that when it is at right angles with the side of the main carrying frame or trolly, it projects from 3 to 4 feet, or any length at which it is desired to cut the coal; and the whole machine is so made as to be either self-propelling along the rails as the coal is cut away, or it can be arranged to be propelled by hand, rope, or other suitable means.

"Figs. 346 and 347 of the accompanying drawings represent, respectively, end and side elevations of the Economic machine, and Figs. 348 and 349 show the details of the cutter bar. The cutter bar is shown having the spiral groove in the form of a screw running from end to end. At regular intervals round the periphery are fixed a number of suitable cutters projecting above the surface of the bar and firmly fixed therein. When the cutter bar is made to rotate, and is pressed against the coal, the cutters cut it away, and the dust and cuttings fall into the spiral groove, and, by the rotation of the bar, are drawn away from the cutters, leaving them clean and not liable to clog. The whole of the bearings carrying the cutter bar and shaft are fixed on the circular frame. The cutter bar and shaft are rotated by means of a steam or air engine, as shown in the drawing. The circular frame carrying the cutter bar is in turn carried within another frame or trolly mounted

on tram wheels arranged for running on rails. The circular inner frame is capable of being canted, as before remarked, to a position other than horizontal, irrespective of the outer frame, by means of slots and ear pieces, and is fixed in position by means of bolts and nuts.

"The frame is also capable of being turned round in a circle, after the manner of a turntable, by means of a hand-wheel and worm fixed on the frame or trolly gearing into a suitable wheel attached to the frame carrying the cutter bar."

Hurd and Simpson's Coal-cutting Machine.—One of these machines is described by Mr. Hurd in a paper read by him before the North of England Institute of Mining Engineers. Fig. 350 gives an outside view of one of the coal-cutting machines adapted for undercutting the coal by means of an eccentric wheel with cutters at its edge, driven by two specially constructed air-engines, of 6-inch cylinder and 12 inches stroke, the whole being carried upon a suitable bogie on wheels made ot run upon a tramway line along the face of the coal.

Figs. 351 and 352 show a modification of the machine for cutting in any direction. It will be seen that the arm B, carrying the cutter, is made to turn upon the axle A attached to the framework of the machine; this centre can be raised up or down and the power communicated to the cutters by means of the bevel wheels, as will be readily understood by reference to the drawings. This machine, which can cut in both the roof and thill, and can also nick at the ends, is peculiarly adapted for narrow work. It is thought that no very detailed description of the machine is necessary, as its construction is so simple that the use of the different parts can be understood at a glance. It may, however, be as well to remark that the wheel D, Fig. 350, is provided with cutters which are placed eccentrically; the wheel goes round in the direction of the arrow. The cutters can start from the face and work themselves into the nick, and are so arranged that each group of three cuts the top, centre, and bottom of the groove or nick, as at *a*, *b*, *c*. The cutter wheel is driven by a bevel wheel, the teeth of which, in fact, are cast with it, but are placed underneath to protect them from dirt, and are not visible in the drawings. There are other means provided for driving the cutter wheel, but it is not necessary to describe them here. The cutter wheel is carried by a thin, but strong, steel arm B, the hidden end of which is provided with a wheel through which, by means of gear, motion is communicated to it by hand, and it is made to enter the coal or to withdraw from the groove, or take a direction in front of, or at either side of the machine. The cutters being eccentric to the wheel, they act with greater effect during one half of the revolution than they do at the other half revolution; and while the smaller radius of the eccentric is towards the coal, the machine is drawn forward in the direction of the arrow by a self-acting hauling rope, or chain, which is wound round a drum and actuated by the machine. The leading end of the machine is kept in position on the rails when at work, by a roller B fixed to a differential lever A, with self-acting adjustment to adapt itself to the inequalities on the face of the coal, and this arrangement prevents the machine from getting off the rails when undercutting. These machines are sufficiently portable and compact to run on the ordinary rails into any part of the pit, and can be taken up or down the shaft in the ordinary cages used for winding the coal.

Fig. 353 shows the method adopted for heating and expanding the air supplied to the machine. The air coming from the compressor is made to pass through a retort E containing a perforated crucible C, made of saponite or other suitable material, charged with ignited fuel (charcoal and scrap iron); a check-valve B is provided to prevent the return of the heated air which passes through D to the machine.

Fig. 354 shows an apparatus for upheaving the bottom coal after the top portion has been undercut and removed, and consists of a cast-steel or metal wedge-shovel X, which is forced forward by the screw Y, and the screw is worked round by the lever Z and catch Z′ acting in the toothed wheel Y′; the catch Z′ can be reversed, so that the wedge-shovel can be withdrawn as well as pushed forward. The end of the screw Y works in a socket which abuts against one of the props B, and the adjustable stay C serves to increase the resistance to the pushing of the screw.

The arrangement shown in the drawings is adapted for horses, which are harnessed to the levers O O in the usual way. These levers give motion to a vertical shaft O′, which drives the crank-shaft S by means of the wheel and pinion B and S′. This crank-shaft gives motion to two pistons K′ and J′ working in cylinders K and J. The pistons work in water, which acts as a lubricant, and ensures the full amount of air admitted being forced into the receiver or air-chamber; the compressed air is forced through the valves M M and pipe M′ into a suitable air-chamber A′, which is placed in the frame A. To the upper end of the crank-shaft S is fixed a mitre pinion, which works the shaft N provided with tappets N′, for opening the admission valves L L as soon as the pistons begin to move in the direction for admitting air to the cylinders. To fix the machine securely in the seam, a prop or rod O^2, provided with a head T, passes through the centre of the axis O, and at the bottom it is provided with a screw O^4 and a foot O^5; by moving the nut O^3 the screw fixes the foot against the thill of the mine, and the head R against the roof, thereby securely steadying the machine.

Recent practice in the use of these machines has proved that above 150 yards can be undercut in ten hours, an amount of work which is at least thirty times as great as an experienced workman can do in the same time; but this is a minor advantage, compared with the great safety it affords the miners. By these machines the coal is undercut at night, and in most cases falls without a shot or a wedge being required, so that the miner begins to fill and send out his waggons at once without the necessity of holing the coal himself, which, when the weight is on the face, is a dangerous operation, and necessitates great vigilance on the part of the workmen. As a rule, the miners know to a few seconds, by the sound, when the coal will part, but yet they are sometimes caught. Again, in nearly all cases the speed of the machine is so great that the coal can be undercut and got before the weight of the roof gets on to it. Thus, seams formerly known for their bad roofs, are comparatively safe. Taking the average of coal seams, the usual mode of working involves a reduction of one-third of the quantity gained, into slack, which, of course, is a very serious loss; whereas by the machine the average loss in a 3-foot seam does not amount to more than the one-eighteenth part of the whole. In seams where there is a thin band of stone or dirt the machine can be made to hole in such band, the debris of which can be cleared away before the main coal is brought down, which would enable the coal to be brought to bank cleaner and with much less trouble. In the perfected machines which are at present in use, the speed of work with a pressure of air of 20 lbs. to the square inch may be reckoned at 30 yards per hour in medium hard coal, the groove made being 3 inches wide and a yard deep. Taking stoppages into account for removing and adjusting the machine, the average may be taken at one-third less. If it is convenient to have a working pressure of 50 lbs. to the square inch, the cutting rate can be increased to 1 yard per minute. This extra rate, however, is not economical, on account of the additional wear upon the cutters, although the machines are of sufficient strength to resist the increased rate without breakage or heating. With respect to the replacement of the cutters, it may be remarked that they will run from six to eight shifts of nine hours each, without sharpening, in the very hard stone coal which is being undercut for the Wigan

Coal and Iron Company, with an air pressure of 20 lbs. to the square inch, and the average rate of progress 7 yards an hour. The usual price charged for undercutting a medium hard coal by contract is 1*s.* 6*d.* per yard, the contractor finding the necessary machines, and one workman to each, and the miners laying the roads and preparing the faces, which must not be less than 30 yards in length. If worked in pillar and stall, the rates are increased in proportion to those paid to the miner; this system is not only expensive, but very dangerous, and involves costly ventilating arrangements; and it may be predicted that it will certainly go out of use by the adoption of machinery; first, because it is much easier to ventilate a straight face; and secondly, because the coal when undercut comes down before the roof has had time to settle, and this to such an extent that at many places where pillar-and-stall work is carried on, under the impression that the roof is so bad that faces of 30 yards could not be maintained with safety, it has been found that when the seams had been struck to boundaries, and worked up half board and half endways on, and undercut by machinery, they have been worked with an open face of 1000 yards in length, with more safety and better ventilation than before. In reference to the work done by the heading, tunnelling, or straight work machine, already described, the contracts are based on different terms, and with reference to the forward yardage only. For example, the contract price for making three cuts 1 yard deep in medium hard coal, that is to say, two side cuts and one bottom cut (or, if preferable, a top cut) in a heading 5 feet 6 inches high, by 9 feet wide, is from 10*s.* to 15*s.* a yard forward. When these cuts are made, if necessary, a $1\frac{1}{2}$-inch drill is adjusted to the machine, and in two minutes a shot hole 3 feet deep is made. The machine is then run back a short distance, when a shot is placed and fired. During the whole time ventilation is kept up by a slight outlet of compressed air, which arrangement saves the expense of bratticing.

The average time occupied in making the cuts, with 20 lbs. pressure of air, in such a heading, is sixty-three minutes, which is about five times the speed of driving it by manual labour, which only gives at best about 3 to 4 yards in twenty-four hours.

The air-compressing machinery has been designed to obviate the very great expense of laying down the pipes to transmit the compressed air from bank to the machines in the face. The compressing machinery here shown can be placed conveniently near to the face of the coal, and can supply air to machines to undercut a large area without being moved. It is worked by horses, or by specially worked steam generator, which the author intends making the subject of a future paper.

Firth's Coal-cutting Machine.—Firth's machine, which was one of the earliest in the field, is shown in Figs. 355 to 358. It is constructed for working a pick by means of a bell-crank lever, so as to give an action similar to that of the ordinary pick employed in hand work.

The pick A is fixed in a socket in one of the arms of the bell-crank lever B, the other arm of which is worked direct by the piston rod of the horizontal cylinder C. The slide-valve D, Fig. 358, for the admission and discharge of the compressed air by which the machine is driven, is an ordinary slide, worked by a tappet roller E upon the piston rod; the machine is thus self-acting as regards the strokes of the pick, which is started to work as soon as the compressed air is turned on by the stop-cock F in the supply pipe G. The machine is mounted upon four wheels running upon the ordinary rails of the colliery, and is advanced the requisite distance between each blow of the pick by a hand-wheel H, connected by gearing with the two hind pair of carrying wheels. The two pairs of wheels are coupled together, in order to render the full adhesion available for the

forward motion of the machine; and by this means it is found that sufficient adhesion is obtained without the necessity of laying down a special rack-rail for the feed motion.

As the return of the pick after each blow is made by means of the self-acting tappet motion working the slide-valve, it is necessary that the tool should go to the full extent of its stroke at each blow, before it can be withdrawn again. The amount of feed between each blow has therefore to be regulated by the attendant, according to the hardness of the seam of coal in which the machine is cutting, so that the pick shall complete an entire cut at each blow. In the event, however, of the pick being advanced too far at any blow, so as to put too much work upon it, and stop it before the stroke is completed, it is only necessary to draw the machine back again by means of the hand-wheel H, until the pick is released from the cut; the unfinished stroke is then completed, and the pick goes on working again the same as before the stoppage. In order to allow of altering the height at which the pick performs the holing in the coal, the socket K carrying the pick is made to slide vertically upon the shaft of the bell-crank lever B, the height of the socket being adjusted by the forked arm J, controlled by the screwed rod and handle L.

One of these pick machines worked the whole of the undercutting in the West Yorkshire Coal and Iron Company's colliery at Tingley, near Leeds, holing a seam of coal 3 feet 8 inches thick; and the compressed air for driving it was supplied by an air-compressing engine at the surface, with steam cylinder of 20 inches in diameter and 3 feet stroke, working an air-cylinder of 18 inches diameter and the same stroke, and compressing the air to about 50 lbs. the square inch pressure. The depth of the pit is 170 yards, and the air is conveyed down the shaft and along the mine in $2\frac{1}{2}$-inch cast-iron pipes, with a $1\frac{1}{4}$-inch wrought-iron pipe laid up the bords to the working faces, and then a $1\frac{1}{4}$-inch flexible tube to the coal-cutting machine. Small air-vessels are placed at intervals of 500 yards along the air main, for the purpose of maintaining the pressure of the air at the machine when working at a considerable distance in the mine; the machine is worked at a distance of as much as a mile from the shaft.

In a trial of this machine, it is found that a pick of 75 lbs. weight, cutting a groove to a depth of 24 inches in from the face, gave about seventy-four blows a minute. At the colliery the coal was got by the long-wall system of working, the machine working along a straight face of 50 yards at one of the banks. The time occupied by the machine in undercutting a length of 56 feet was twenty-five minutes, including all stoppages for clearing rubbish out of the hole, and for backing the machine when the pick occasionally made an incomplete stroke. The machine was then run back to the starting point, and set to work again with a longer pick of 90 lbs. weight, completing the previous cut to the final depth of 3 feet 9 inches from the face. With this pick the blows were about sixty a minute, and the half-length of 28 feet was undercut in seventeen minutes, including all stoppages. The time occupied in running the machine back and changing the pick was sixteen minutes. The machine in this case was working at a distance of about a mile from the bottom of the shaft.

From this trial it appears, that in undercutting to a depth of 24 inches in a single course, the work done by the machine was at the rate of about 30 square yards an hour; and in undercutting in two courses, to the total depth of 3 feet 9 inches, the work was done at the mean rate of about 15 square yards an hour, including the time required for running the machine back and changing the pick.

The width or height of the groove cut out by the pick is 2 inches at the inner extremity,

widening out slightly towards the face of the coal. It is necessary to stop the machine at intervals, in order to clear out the rubbish left in the hole; and the rails in front of the machine have also to be cleared of the material thrown out by each return stroke of the pick. Two men are required to attend to the machine, one working the hand-wheel for the advance of the machine, and the other clearing away the stuff.

A good criterion of the actual rate of working that may be safely reckoned upon with this machine in regular practice is afforded by its performance upon an occasion when it was kept continuously at work for twenty-four hours consecutively, on 21st and 22nd of May, 1868. During this time the machine was employed upon five different banks of coal successively, requiring accordingly to be shifted four times for the purpose. The average depth of holing was 3 feet 6 inches, and the total length of work completed to that depth during the twenty-four hours amounted to 257 yards. This gives the practical rate of holing by the machine at rather more than 12 square yards an hour, including all stoppages for clearing the pick in working and for shifting the machine on the completion of each separate length of bank.

Some improvements in this machine have been reported recently. It is stated to be working in a seam 2 feet 8 inches thick, and to have undercut a face of 500 yards in length to a depth of 3 feet, using a new form of the pick which removes the dirt as it proceeds.

Mr. Firth has also recently invented a method of fitting picks with movable cutting points. It is the general custom to work picks with points solid, that is, the point and pick in one piece. By this arrangement it becomes necessary to take the whole pick out of the pit whenever blunted, in order that it may be sharpened. The improvement consists in making a boss on that part of the pick nearest the point. In this boss is a socket of any suitable shape, by preference a circular taper socket, the loose point being cottered into the socket against a piece of indiarubber, or other suitable substance, at the bottom of the socket or around the outer edge of the socket, so that when the blow is given some part of the strain is taken off the point. The edge of the socket is brought as close as possible to the point, for as the socket must enter the groove made in the coal, and must be clear of the top and bottom of the groove, and as in some cases the groove is not more than $1\frac{3}{4}$ inch in height, it will be readily seen that the closer the socket is to the point the greater the resisting strength of the point.

R. F. Martin, speaking of this machine, remarks as follows:—

"The pick machine of 'Firth' has done much good work as pioneer in times past. It must, however, be remarked that this machine furnishes a capital instance of a general law in the history of invention. When first attempts are made to supersede hand labour, they almost invariably imitate, as closely as they can, the most approved method of doing the work by hand. Afterwards, when it is seen more clearly what are the true conditions of the problem, as apart from the fact that it must be performed by manual labour, the form of the machine is altered accordingly, the general tendency being to simplify and not to elaborate the machines employed. The picks of Firth's machine would seem to be far too heavy, as if the fact were ignored that the effect of an impact will vary as the mass and the square of the velocity with which it strikes. This is in fact the question of English *v.* American ordnance over again; and as the latter found that their large masses and low speeds had a greater 'racking' effect upon a wooden frame than the smaller mass and high velocity of the English ordnance would have, so it is possible that Mr. Firth's heavy picks and low rate of impact may be found to produce a more satisfactory result than would have been imagined. The author

brings this forward in the hope of eliciting some information on a curious question, and one which is well worth discussing in connection with the speed at which coal cutters should be driven."

Carrett and Marshall's Hydraulic Coal-cutting Machine.—Carrett, Marshall, and Company's coal-cutting machine is deserving of attention as illustrating a different principle of action. It works after the manner of a hand-plane, cutting into the coal as a scoop cuts into cheese; it is said to be capable of working effectually in a space only 2 feet high, and of accomplishing more in one minute than seven hundred blows from a pick can in the same time.

It is about 2 feet high, weighs 1 ton, has four legs of adjustable length, and is provided with a holding piece adjusted so as to touch the roof of the drift and hold the machine firmly to its work. The motor is water, under a pressure of about twenty atmospheres or 300 lbs., and supplied through a 2-inch pipe at the rate of 30 gallons per minute. This water pressure acts vertically on a 5-inch piston pressing against the roof, and horizontally on one about the same size, reciprocating 18 inches, and fifteen to twenty times in a minute. There is a pressure of 5000 lbs. against the roof, and the same pressure acting horizontally, forcing three steel cutters, shaped like cheese scoops, into the coal. These cutting tools are 3 inches wide, and penetrate 4 feet, with a power equal to three horses, or eighteen men; and this is effected by a consumption of 50 lbs. of coal per hour to feed the boiler of the engine, which makes the water pressure, and pumps the same over and over again.

The construction in detail is shown in Figs. 559 to 561, which consist of a front elevation, a plan, and an end view.

The machine in operation fixes itself dead fast upon the rails during the cutting stroke, and releases itself at the back or return stroke, and traverses forward the requisite amount for the next cut without any manual labour. Should the tools be prevented from making the full stroke at one cut, they will continue to make more strokes at the same place, until the maximum depth is attained, when the machine will move itself forward the required amount for the next cut. Thus, at one operation, a uniform straight depth is attained, parallel with the rails, inducing an even fracture when the coals are brought down, and thereby a straight line for the new coal face. There is no percussive action, either against the roof or into the coal, but simply a concentrated pressure, producing a steady reciprocating motion at fifteen strokes per minute. There is, consequently, no dust or noise, and little wear and tear. For the same reason, when cutting pyrites, the tools throw out no sparks, and the workman can hear any movement in the coal or roof.

The required height from the line of rails in the "holing," "kirving," or "baring," varies in different mines; it follows that the hydraulic cutting cylinder, and its direct-action cutting tools, have sometimes to be arranged *above* the carriage, and sometimes *beneath* the main carriage, or close down upon the rails, as illustrated in the elevation. The first figure is the main carriage, with four wheels far enough apart to allow the machine to be placed longitudinally when being transported from place to place. The screws Y Y are for raising and lowering the carriage and its cylinder and cutting tools. The pinion Z and the segmental rack H regulate the desired angle of the tools cutting into the coal face, and the two nuts x x at each end of carriage regulate the angle required, when necessary that it shall not be in the same place as the rails. A A A are the cutting tools, B the cutter bar, N a guide roller for the same; D is the main cylinder, with a self-acting hydraulic valve-motion, which passes a portion of its water alternately above and below the piston of the holder-on, which thus rises and falls without percussion, and follows the uneven line of the roof of the mine, so that the required stability is given to the machine for the time being, an instant before the

cutters enter the coal. The "holder-on piece" can be any length necessary to bridge over gaps in the roof; it is loose on the pin F and droops at its leading end to enable it to ride over the varying projections in roof.

The traverse motion is actuated by the pin *b*, which connects the cutting bar with the piston rod, and at the termination of each end of its stroke actuates the lever *d* in both directions, which operates on the pawl *e*, which causes the chain pulley to revolve on the chain *i*, made fast ahead by an anchor-prop between floor and roof.

Although the length of stroke of each cutting tool is 18 inches, the practical cutting length is 16 inches, and, consequently, the three cutters jointly give a total effective depth of 4 feet at each stroke of the machine, finishing the work as it goes along.

The mechanism employed consists of a hydraulic reciprocating engine, adjustable to any height or angle, having a self-acting valve-motion. The cylinder is $4\frac{1}{2}$ inches diameter, and lined with brass, and the piston made tight with ordinary hydraulic leathers, which can easily be removed. Within the piston rod is attached the cutter bar of steel, carrying the tools or cutters. These can be varied in number to suit the depth to be holed at one operation. The cutting tools are of double shear steel, can be easily made, and are very strong, and can be removed and replaced in a few moments; they can be readily sharpened on an ordinary grindstone. The cutter bar is also movable, when transporting the machine from place to place, for which purpose the main cylinder is, for the time being, placed longitudinally with the rails.

The machine is about 3 horse-power, and weighs 1 ton, and will work either right or left. It is self-acting in all movements, and will ascend steep gradients; being simple in all its parts, it is not liable to get out of order, and is easily managed by an ordinary miner, and can be transported from place to place, on the ordinary rails, about the mine. It undercuts "holes," or "kirves," with a man and boy as attendants, and completes the work with once going over, at the rate of 15 yards per hour, and at any angle and height from floor rails, being suitable for either "dip" or "rise" workings, and is capable of cutting the thinnest seams. The pressure of water which actuates this apparatus can be obtained either from the stand-pipes in the pits, or from pumps attached to any existing engine, or from an engine or pumps specially made for the purpose. The quantity necessary is only what is sufficient to fill the circuit of the pipes, using it over again when desirable, as in the Bramah press. Each machine uses 30 gallons per minute, or about 300 lbs. pressure, according to the hardness of the coal or mineral to be operated upon. In cutting the shale of the Cleveland iron-stone band a somewhat greater pressure is found to be necessary.

There is no limit to the pressure of water that may be used, nor the distance it may be forced without loss of power, beyond that due to its friction along the pipes. The same water pressure is also applicable to work pumps and rotary engines for hauling, &c., and other requirements in the mine, at a distance from the engine power. In cases where there is a fall of water, say of 100 lbs. pressure, it can be "intensified" by a self-acting machine to 400 lbs. pressure, to work the coal cutter, but sacrificing three-fourths of its bulk, which is set free.

In arranging the engine and pumps required to make a "continuous stream" of water pressure for working these machines, it is preferable to have two steam cylinders, so that there be no dead water. They are constructed to work one, two, or four machines. Pipes, if for one machine, are of 2-inch bore, wrought iron, a superior quality of gaspipes strong enough to stand 500 lbs. pressure. These pipes are screwed together in the ordinary manner, and adapt themselves readily to the

irregularities of the floor of the mine. A flexible pipe $1\frac{1}{2}$-inch bore, suitable for the same pressure, allows the machine to traverse.

Requirements of a Coal-cutting Machine.—R. F. Martin, whom we have already quoted, lays down a set of conditions which every coal-cutting machine should fulfil. As this gentleman's great practical experience enables him to speak authoritatively on the subject, we give these conditions as set forth in the following statements.

" The conditions which should be looked for in determining the value of any coal cutter would seem to be :—

" 1. So long as compressed air is the vehicle for communicating the power to the machine, it is out of the question to look for any considerable amount of *expansion.* The proportions should, therefore, be designed to meet this; thus short strokes, quick speeds, large ports, and two, or, if possible, three cylinders, will probably give best results.

" 2. The materials of which the whole machine is constructed should be the best known for combining rigidity and lightness. Cost must become a secondary consideration altogether. Thus the frame should be of steel, cast and annealed, or wrought; the shafts, toothed wheels, cutter and bearing wheels all of steel; and generally the workmanship should be the best that could be put into it; and the design should combine the usual *strength* and *power* which should characterize all colliery machinery with the best modern practice of mechanical engineers.

" 3. Undoubtedly the fewer the working parts the more efficiently the machine will do its work. The Winstanley form of machine, with the addition of a self-acting 'feed,' would be a good model to follow here.

" 4. The following details should be noticed. The wheels should, if possible, be set to run on the regular gauge of the pit. The machine should be easily adjustable for height, so that the cutter may be set to cut at any required distance above the floor. In arranging the self-acting feed, which must, it is thought, sooner or later be adopted by everyone, it should be made capable of being regulated easily in amount; and also a provision should be made for enabling the feed apparatus to slip when a certain pressure is applied to it.

" 5. The cutter itself is a point which should be most carefully discussed. Of the two examples now before us, viz. the circular cutter or saw, and the parallel cutter or endless band, the balance of advantages appears to be with the former. It would appear also that a small feed and quick speed, or, what is the same thing, large number of cutting points, will give the best result. This, however, will vary from one seam to another, and the following must be among the first things to experiment upon at any fresh pit:—

" (1) What is the greatest speed at which the cutters can be driven?

" (2) What is the sharpest angle at which the cutting edges can be set?

" (3) Is the floor of the seam sufficiently level to allow of a circular cutter being employed?

" 6. Assuming that the circular form of cutter is the form to be adopted, it will be observed that the side strains upon the flanges of the grinding wheels will depend very much upon the position of the hauling chain, and that they will be the least when the chain is as close as possible to the coal face. Also that the side strain upon the front wheels will always be greater than upon the hind wheels; that the longer the body of the machine, and therefore the longer the wheel base, the less these side strains will be; and that so far as these strains are concerned, it would be better to make the frame of the machine project in front, not behind, the line of the centre of the cutter.

"7. Atmospheric engines have often been subject to great difficulties from the freezing up of the exhausts. This will need special consideration.

"8. The couplings of the air-pipes are often a great source of waste of power. A good coupling, readily joined up and uncoupled, and not liable to leak, is much wanted. The coupling of the carriage pipes, belonging to the 'Westinghouse' brake, is worthy of attention here, as most ingenious and most successful in a very difficult position.

"9. The depth of the holing cut by the machine, which amounts in those I have examined to barely 3 feet, should be capable of considerable extension, to suit the requirements of all districts."

The writer in concluding his comparative examination of the Baird, Winstanley, and Gillot machines, adds:—

"Having traced the particulars of some of the most successful coal cutters in this country, and compared the work done in an average north country and south Yorkshire coal seam, and a Lancashire seam of such small height, and so hard as to be far beyond the average in point of difficulty, we have arrived very clearly at the following results:—The work of two men and one boy at the machine, and one man at the engine, will cut coal at the rate of 30 yards per hour, 3 feet under, in two of the seams, and even in the hard Hetton coal seam it is now cutting as much as 13 yards per hour, 3 feet under.

"If we allow 10 yards of face as the average amount of holing per man per shift, the former rate of work will give, in a nine-hour shift, 270 yards of face, or the work of twenty-seven holers; the latter rate about 120 yards, or the work of twelve holers; the average of the two will be the work of twenty men at least. We may, then, hope to save some sixteen men, on an average, for every machine put underground in even a fairly favourable position.

This economy of labour is at present even more important than the economy of cost; but the saving in money is, at Wharncliffe Silkstone at any rate, none the less remarkable than the saving in men. The saving, as given above, amounts to over 5*d.* per yard upon the labour, and 25 per cent. more round coal and less slack; and there would appear to be nothing to charge against this gross saving, except interest on capital, wear and tear, and the coal and stores used at the air-compressor, and the machine.

"These facts must go a long way to justify the most careful and even costly experiments; and the author has only to add his own firm conviction that the adoption of coal-cutting machinery is only a question of time; and that our midland district is, of all the districts in England, *the one* in which it can most readily be employed. Whatever may be the ultimate shape which coal cutters may assume, the most likely form of machine with which to experiment at present is that of a circular cutter revolving on a frame, driven by the simplest and the strongest form of air engine which can be devised, with a self-acting 'feed;' and all details will have to be designed specially for every seam, almost for every pit."

Coal-falling Machine.—The danger of firing charges of gunpowder in an atmosphere laden with explosive gas has led to several attempts to produce a machine which should be capable of breaking down or "falling" the coal after it has been undercut, more easily and quickly than the ordinary wedge driven in by hand. The appalling accidents that have occurred of late, and that have been attributed to the firing of a "shot," have served to direct the attention of inventors more earnestly to the subject, and these breaking-down machines have been improved in design and construction, and in several instances successfully applied in practice. A similar mode of action is

adopted in all of these machines. A hole is first bored in the upper part of the seam which has been "holed" or undercut, as for a shot; an expanding bar from the machine is then inserted into the hole, and the bar expanded vertically, so as to bring upon the coal a force tending to break it down. One of the most successful of these machines, which are usually actuated by hydraulic power, is that known as "Bidder's." This "breaker" has been adopted in numerous collieries with marked success. A general view of it is given in Fig. 362.

The principal machine consists of a small hydraulic press, weighing about 60 lbs., and of 15 tons power. To this press is attached a pair of steel tension straps, bent in the form of a tuning-fork, and which are connected with the press by a collar. At the end of these straps is first placed a clearance box, about 4 inches long, and upon each side of the straps expanding pieces (also made of steel), which exert a pressure at the sides of the hole, and are 15 inches long. The points of a pair of twin wedges, 15 inches by 3 inches, constituting one wedge, are then inserted in the expanding piece, and the machine is fixed in the hole. The hydraulic press, having been charged with about three pints of water, which may be used over and over again without loss, is then worked by a man by means of a small handle, and the ram from the cylinder is forced out, thus driving up the pair of wedges between the expanding pieces, giving a lateral extension of about 3 inches. This not being in all cases sufficient to bring down the coal, the press is withdrawn, and the relief valve opened, thereby allowing the water to return to the reservoir. A second wedge is then inserted between the two twin wedges by means of a small rod, five-eighths of an inch in diameter, and, the press being again connected, this wedge is driven home in the manner before described. By this means an additional expansion of 3 inches is obtained, making a total expansion of 6 inches, which in most cases is found sufficient; but a third wedge can be applied, if necessary, and the expansion thus increased to any reasonable extent. In this manner as much as 10 or 12 cwt. of coal have been brought down in ten minutes.

The drilling apparatus, the principal part of the machine, consists of a screw 4 feet by $1\frac{1}{2}$ inch in diameter, to the end of which is attached the drill. The fulcrum for taking the resistance of the screw is obtained by inserting a bar of iron in the coal at the side of the place selected for the hole which the machine has to drill. This small aperture is made by punching with the ordinary instrument a hole 10 inches deep and 1 inch in diameter, and the time occupied in making this preparation is usually about four minutes. The small bar for taking the resistance of the screw is then inserted, and it may either be fixed at the side or in the face of the coal, as the case may require. The screw is then adjusted to this bar, and the drill driven in the coal by a man turning the handle at the end of the screw. The time occupied in drilling this hole for the machine, 3 inches in diameter and 3 feet 6 inches deep, is from ten to fifteen minutes, according to the hardness of the strata; and if it is necessary to drill the hole in such a position that the rotary motion of the handle by which the screw is propelled cannot be obtained, a ratchet may be used, so that under any circumstances no difficulty can be felt in procuring the required motion.

The first trial of the machine was made at a pit belonging to the North Staffordshire Coal and Iron Company, at Talk-o'-th'-Hill, in a heading in what is called the Eight-feet Banbury seam of coal, at a depth of 350 yards from the surface, and under ordinary working circumstances, so far as the place selected was concerned.

Considerable difficulty is always found in fairly testing a machine under such circumstances as these, but, notwithstanding every disadvantage, the hole for the machine was drilled, and about

4 tons of coal brought down in twenty-five minutes. A workman in charge of the place was asked how long it would have taken him to have drilled the hole and fired the shot, according to the present system of blasting, and he considered that an hour would be required for the purpose, and a pound of gunpowder used, at a cost of 5*d.*

The superiority of the machine was, therefore, evidenced by the saving of thirty-five minutes in time, and 5*d.*, the cost of powder, and the work was done without the smallest danger to anyone. Two further trials of the machine were made in other parts of the workings, in both the Seven and Eight-feet seams, with results equally satisfactory. The mode of using the machine in the working of coal would be to provide each set of colliers with a pair of steel tension straps, and the machine could easily be carried about by a man like a double-barrelled gun under his arm, from place to place. It would thus be necessary to have only one press for a large number of these places: the entire cost of the machinery is very small.

CHAPTER III.

HAULING AND HOISTING MACHINERY.

THE conveyance of the produce of a seam or a vein from the working places to the shaft, and the raising of it through the shaft to surface, constitute one of the most important questions of mining engineering. Upon this question indeed, the profitable working of a mine may largely depend. Hence it has happened that much attention has been directed to the subject, the outcome of which has been that, within the past few years, rapid and great progress has been effected. The improvements made have not been confined to the engines employed to furnish the motive power, nor even to these and the means and methods adopted for applying the power; but they have extended to the vehicles in which the produce of the mine is transported, and have become manifest in more suitable designs and in modes of construction better adapted to the conditions under which the vehicles have to be used. These conditions, designs, and modes of construction have been fully treated of in the author's work on 'Mining Engineering.' In the present work, such a treatment of the subject would be out of place; but it will be necessary, in order to appreciate the advantages of the various forms of vehicle adopted, and the differences in the manner of their construction, to repeat here some of the considerations which, in the work referred to, have been carried to greater length. The vehicles in which the transport is effected, which vehicles are denominated by miners "tubs," "cars," "waggons," "corves," "kibbles," and "cages," claim, for the sake of clearness, prior consideration, as a complete understanding of the conditions under which these have to work is necessary to a due appreciation of the merits of the motor engines employed to move them.

TUBS, WAGGONS, OR CARS.—The vehicle known under the several names of "tub," "waggon," or "car," is that in which the mine produce is conveyed from the working places to the shaft, and commonly from the bottom of the shaft to surface or "bank." It consists essentially of a "body," usually rectangular in form, to contain the load, and of "wheels and axles," to carry the body. These two parts of the tub will influence the system of haulage differently, the former having reference to the conditions affecting capacity, the labour of loading, and the height of the working places, and the latter relating more directly to the force of traction to be exerted upon the load.

Wheels and Axles.—The form and construction of the wheels and axles of a tub, and their arrangement relatively to each other, influence in no small degree the question of haulage considered with respect to the requisite force of traction. The principal points to be taken into account, in a consideration of this nature, are the kind of connection made between the wheels and the axles, and the diameter and the form of the rim of the wheels adopted. There are two kinds of connection made between the wheels and the axles of vehicles; in the one kind, we have the wheels fixed upon the axles in an invariable manner, so that the latter are compelled to revolve with the former; and

in the other kind, the axles are fixed and the wheels revolve freely upon their extremities, which, in such a case, receive a particular form, and are described by the term "journals." When the connection is of the first kind, the wheels are mutually dependent, that is, the angular motion of each must be equal and take place in the same direction, or, in other words, they must turn in the same direction and with the same velocity. When the connection is of the second kind, the wheels are completely independent of each other, that is, they may revolve with different velocities and in contrary directions. Thus it is evident that the nature of the connection will, under certain conditions, operate to facilitate or to impede the work of traction.

It will have been observed that the system of fixed wheels is invariably adopted upon railways, and that the system of free wheels is as invariably applied to vehicles running upon common roads. The reasons for this are plain and easy to be understood. On a railway, the motion is in a straight line, and the surfaces over which the wheels of the vehicles roll are perfectly even. These are the conditions always sought; in practice it becomes necessary to modify them frequently, as, for example, when curves are adopted; but curves are avoided whenever possible, and when circumstances compel their adoption, they are made of the largest possible radius in order to approximate to the straight line. On common roads, on the contrary, the motion of a vehicle is continually in a curved line. It is impossible that it should be otherwise, when the wheels are not guided. But irrespective of this, road vehicles have to be very frequently directed out of their course to avoid other vehicles and obstacles of various kinds, and to be turned off at a sharp angle, or completely round in a small space. And again, the surface of a common road is very far from possessing that regularity which is characteristic of the railway. Thus the conditions of motion upon a railway and upon a common road are essentially different, and these conditions determine the kind of connection between the wheels and the axles.

When the motion of the vehicle takes place on a curve, as in the case of a common road, the arcs passed over by the two wheels are unequal, and the degree of the inequality will obviously increase with the distance of the wheels apart. One of the arcs will be reduced to nothing, if the vehicle be made to turn upon one of its wheels as a point of support; or they may be equal, but the motions contrary in direction, if it be made to turn about its centre of gravity. If the wheels were mutually dependent, as one would be required to revolve more rapidly than another, or the two be required to revolve in contrary directions, it is evident that one or both of the wheels must slide, and the same result will follow from one wheel passing over an irregularity in the road. But when the wheels are independent of each other, the requisite inequality of motion presents no difficulty whatever, since each wheel is free to move with the velocity and in the direction needed. Hence it appears that the adoption of the fixed wheel on the railway and of the loose wheel on the common road may be perfectly justified.

A consideration of the underground roads of a mine will show that both classes or sets of conditions exist. It is altogether impracticable to construct these ways with the accuracy of direction and the solidity attained upon ordinary railways. Great irregularities have to be encountered; frequent curves of short radii occur, and often the tubs have to be turned from one road into another by hauling it bodily round upon a smooth floor. Not unfrequently the tubs have to be run along roads unprovided with rails, when, of course, the conditions of the common road present themselves. Thus it will be seen that, on the underground roads of a mine, the question is greatly complicated: and hence it has happened that opinions are divided respecting the most suitable kind of connection.

In some mines, tubs with wheels upon revolving axles are used; in others, tubs with wheels upon fixed axles. And it will be found, when full account is taken of all the circumstances of the case, that both of these systems may be justified. In this, as in all other matters relating to mining, we have to deal with conflicting requirements, and in order to effect the best attainable compromise, we must carefully consider and accurately appreciate all the determining conditions.

It would, however, appear that the system of loose wheels is generally more applicable to the conditions prevailing upon underground railways than that of fixed wheels, and that, consequently, its adoption is desirable wherever it is impracticable to lay out the roads with great regularity. It is, however, possible to combine the two systems so as to obtain some of the advantages of each, and various devices have been adopted to render the combination as advantageous as possible. The most obvious mode of combining the two systems, and one that has been extensively adopted, consists in fixing one wheel to the axle, and leaving the other loose upon a journal, the arrangement being such as to have one fixed and one loose wheel upon each side of the tub. So long as the line is straight, this system acts similarly to that in which both wheels are fixed; but as soon as a curve is entered upon, the loose wheel takes the velocity necessary to prevent slipping. In order to assimilate this system as much as possible to that of fixed wheels, the loose wheel is made to turn with a moderate friction. Another method, adopted in Silesia, and more recently in some of the French collieries, consists in having as many axles as wheels. In this method each wheel is fixed upon its axle, and a pair of wheels corresponds to two revolving axles parallel to each other. Such a system solves the problem satisfactorily; but it possesses the disadvantage of complication.

Besides these combinations of the two principal systems, other expedients are resorted to for the purpose of rendering fixed wheels capable of running over curves without occasioning a great increase of resistance. Some of these expedients have reference to the road, and will therefore claim consideration in another place. One device consists in making the wheel conical towards the flanges. This form of the wheels is favourable to the stability of the tub on a straight line, and also greatly facilitates its motion over a curve. It is easy to see how these results are obtained from conical wheels invariably fixed upon their axles. If we suppose the tub moving upon a straight piece of line, and driven by some cause to one side, the radius of the wheel on that side will be increased, and that of the wheel on the other side diminished. The tendency of the larger wheel to progress more rapidly than the smaller will immediately restore the tub to its normal position upon the rails. If we suppose, again, the tub to be entering upon a curve, it will be evident that the force of inertia will throw the tub against the outer rail, and bring the flange of the wheel on that side into contact with the inside of that rail, as already pointed out. But this shifting of the tub in the direction of the outer rail has the effect of increasing the radius of the wheel on that side, and of diminishing, in the same proportion, that of the wheel on the other side; and hence it is clear that the outer wheel will, at each revolution, advance through a greater distance than the inner wheel, as required by the greater length of the arc on that side. On curves of a large radius, this expedient gives very satisfactory results.

In consequence of the relative obliquity of the axles and rails upon curves, it becomes necessary to allow the wheels a certain amount of play, that is, to space the rails wider apart than upon those portions of the line which are straight. The shorter the radius of the curve, the larger is the amount of play required, but generally it will be about three-quarters of an inch, or the double of that allowed in the straight. This play will necessitate the adoption of wheels of considerable breadth, as otherwise

a lateral movement, such as occurs during motion round a curve, would cause derailment. A moderate breadth of wheel is also favourable to haulage along the working face, and in other situations not provided with rails. The form of the flange is a question of some importance, since the facility with which derailment takes place depends in a great measure upon it. The section adopted upon ordinary railways is shown in Fig. 363; but the curve is somewhat too short for coal tubs. A form commonly adopted on underground tramways is represented in Fig. 364, which, in consequence of the absence of all curvature, offers great resistance to derailment. An objection to this form, however, lies in the fact that should the flange get upon the rail it has no tendency to slip off, and to thereby restore the wheel to its proper position. A section formed of two lines, one straight, the other curved, and joined to the former by a small circular arc, has been proposed as fulfilling all the conditions required. This section, which is shown in Fig. 365, offers almost as great resistance to derailment as that represented in the last figure, and it possesses besides a tendency to return to its position, if it should from any cause get upon the rail. This quality is very important in a flange, for not only does it prevent the delays consequent on getting off the line, but it greatly facilitates the placing of a tub upon the rails. The material of coal-tub wheels is generally cast iron, to increase their durability. Mr. N. Wood's observations showed that the relative durability of unchilled and chilled wheels was as 39 to 63. Lately, steel has been adopted for colliery wheels, with very good results.

Bodies of Tubs.—That portion of a tub which is known as the "body" is also deserving of careful consideration, inasmuch as its influence on the question of haulage, though less than that of the wheels and axles, is yet great. The body or box part of a tub commonly consists of oak, three-quarters of an inch or an inch in thickness, set upon an oak framing below, and bound with iron to give it strength. Sometimes the body is constructed wholly of iron. Such tubs are very durable, but they are not easily repaired; their weight is about the same as that of wooden tubs.

Lightness is a desirable quality in a tub, since it is important that the dead weight should be reduced as much as possible. Hence that form should be adopted which, with a given weight of material, affords the greatest carrying power. The form which best fulfils these requirements is the rectangular box, and this is therefore generally adopted.

In the design of a tub, there are two features that demand particular consideration, namely, its capacity and its height. Obviously the conditions which determine the latter will have some influence on the former, but besides these, there are others which relate to capacity alone. In order to diminish the proportion of the dead weight to be moved, it is desirable that the tubs should be of large capacity, and the same quality is required by other circumstances connected with the matter of haulage. But a limit in this direction is fixed by the necessity for having tubs capable of being readily handled. It must be borne in mind that the tubs have to be dragged or pushed along the working face; that they have to be lifted and turned at the junction of lines that run in directions perpendicular to each other; and that, in consequence of the imperfections of the road, they frequently get off the line, and have to be lifted on again with little delay. Also, the onsetter and the banksman are required to drag and push the tubs over the tram-plates at the bottom and the top of the shaft, and to quickly run them on or pull them off the cage. Hence it is highly important that the weight should not be too great for one man to deal with. This condition will limit the capacity of a tub, irrespective of other considerations. Moreover, as economy often requires that the operations of haulage should be performed or conducted chiefly by boys, the weight to be dealt with should be

kept within the limits of their strength. For these reasons, a capacity of 8 cwt. is not often exceeded. Another circumstance that tends to keep down the capacity of a tub is the narrowness of the roads in a mine, for as the dimensions can be increased only in one direction, the limits of convenience are soon reached.

The height of a coal tub is limited mainly by three circumstances, namely, the stability of the vehicle in transit, the difficulty of loading it at the working face, and the thickness of the seam. It has been shown that to comply with the conditions prevailing underground, tubs have to be made narrow, and that, moreover, the curves there existing are very sharp; hence it will be evident on reflection that height is inconsistent with that degree of stability which is requisite. Also, it will clearly appear that height in a tub is unfavourable to the operations of loading, since the mineral has to be lifted into it. This is a question of very considerable economical importance, and it is deserving of more attention than has hitherto been given to it. But irrespective of these limiting circumstances, that of thickness of seam may operate to compel the adoption of tubs of low height. It is easy to see that when a seam of coal is thin, it becomes highly desirable, if not absolutely necessary, to use vehicles of such dimensions as will not require the expenditure of additional labour, in ripping down the roof in order to give sufficient height; and it will plainly appear that, as this circumstance limits the height, it will also influence in some degree the capacity of the tub and the diameter of the wheels. Thus numerous conditions combine to limit the dimensions of coal tubs, and it will be prudent to keep within the limits imposed in designing the rolling stock of a colliery. In some instances, tubs having a capacity of 11 cwt. have been adopted, but it must be obvious that the disadvantages incurred by the adoption of such cumbrous vehicles more than compensate the gain.

The following examples of tubs exhibit the forms actually in use, and show the various devices adopted for obtaining the greatest possible capacity for given dimensions and for satisfying the other requirements of underground haulage. Figs. 366 to 369 represent wooden tubs used in England. It will be seen that they are strongly built, and experience has proved that when constructed in this way the cost of maintenance is very little. Three forms are illustrated. In those shown in Figs. 366 and 367 the body is prismatic, and extends over the wheels; in Fig. 368 the body is pyramidal in form, and is brought down to the level of the axle. The latter form is very commonly adopted for coal and other mineral tubs. In different parts of the country, the design and construction of tubs vary somewhat from those illustrated, but in all essential particulars they resemble one of these types. Even when iron is employed as the material for the body, the same forms are adhered to as best fulfilling the requirements of underground carriage.

In Continental countries, the question has received greater attention than in England, in consequence of the greater irregularity of the seams and the increased difficulties of haulage, and hence we find greater variety in the form of the tubs employed. Many of these have been designed to suit special conditions, and are, therefore, not generally applicable. Others, however, have been carefully considered, and constructed to comply with ordinary requirements, and these are deserving of the attention of all practical men. A few years ago, a commission of engineers was appointed by the proprietors of the great Anzin collieries, to examine and report on the coal tubs employed in France, Belgium, England, and Germany, for the purpose of obtaining the best possible design for the new rolling stock. The result of the labours of this commission was the adoption of the design shown in Figs. 370 and 371. The body, which is of iron, is rectangular in form, and slightly bellied. Its length is about 3 feet 7 inches, its breadth 2 feet 6 inches, and its depth 1 foot 10 inches. These

dimensions must, for ordinary circumstances, be considered as somewhat excessive. The axles, which are of the finest quality iron, turn upon steel bearings, which allow considerable play in all directions. One wheel is fixed upon the axle, and the other is loose, and the pairs are arranged so that there is one fixed and one loose wheel on each side. The construction of these tubs will be readily understood from the drawings. Another form of iron tub is in use at the Blanzy mines, and it appears to have satisfactorily fulfilled the requirements for which it was chosen. This type of tub, which is illustrated in Figs. 372 and 373, is also the outcome of a careful study of the conditions to which it must be subjected. The body in this case, as in the preceding, is rectangular, and is slightly narrowed towards the bottom, where it passes between the wheels, as shown in the drawings. The wheels are loose, and, besides this arrangement, the axles themselves are allowed to rotate, so that upon curves, or in case of a defective state of lubrication, the resistance to traction due to friction cannot be great. The oval form of the journal box, shown in the details given in Figs. 374 and 375, allows the wheels to remain upon the rails, whatever the irregularities of the road may be. The distance of the wheels apart is maintained by means of loose washers, well greased, as shown in Fig. 374. This arrangement allows a certain degree of elasticity. Many years of experience at Blanzy has shown that, in consequence of these several devices, the tubs rarely get off the rails, though the roads are in many parts very undulated and irregular. An arrangement, proposed by M. Cabany, and adopted in the collieries at Anzin, is shown in Figs. 376 to 378. The object of the arrangement is to reduce the height of the tub while retaining the same capacity. This result is obtained by elbowing the axles, as shown in the drawings. By adopting this form of axle, the bottom of the tub may be brought as low as desired. The construction of the axles will be readily understood from the detailed drawing, Fig. 378. The body of the tub is very similar to that described as the result of the labours of the commissioners appointed by the proprietors of those extensive collieries.

Since the Exposition of 1867 a commission of mining engineers has been organized in Belgium for the purpose of studying the different forms of cars and tramways in use in the coal basins of the north of France and in Belgium. The car designed by M. Parent has been introduced in many of the mines of the Anzin company, and appears to give great satisfaction. The body is rectangular, 1·10 m. long, 0·778 m. wide, and 0·57 m. deep; capacity, five hectolitres. The body is made of iron, two millimètres thick for the sides, and four millimètres for the bottom. The total weight of the car, with wheels of wrought iron, is 190 kilogrammes, and with cast-iron wheels, 210 kilogrammes. They cost 96 francs each, with cast wheels, and 102 francs with the wrought-iron wheels. These wrought wheels are stamped from a single piece of iron, are 0·28 m. in diameter, and weigh 8 kilogrammes each. They are much lighter and less liable to break than the cast-iron wheels.

At the Chazotte collieries, M. Max Évrard has adopted the Pagat wheel and axle. This is a broad-faced wheel of small diameter, the form and construction of which may be best understood by reference to Fig. 379, which is a section through the centre, showing the end of the axle and the oil-box. This oil-box appears to be the chief merit of this wheel. The end of the axle protrudes within it, and the wheel is held in place by a simple spring linchpin inserted through one of the large holes made in the hub to permit the introduction of the grease from time to time. These two openings are closed by corks *c c* only. A hard grease or tallow is used, and is inserted by means of an injector. When by movement of the wheel the axle warms a little, the grease slowly melts and runs into the bearing so gradually that it need not be renewed oftener than twice a week.

According to M. Évrard, this box once filled with grease is sufficient for running a distance of 16 kilomètres. It holds 128 grammes; the grease costs 52 francs per 100 kilogrammes, and the expense per ton, per kilomètre, is consequently, for the four wheels of a car, 0·0455 fr. These wheels are used under an oval tub car, the capacity of which is limited to 340 kilogrammes.

In Germany, loose-wheeled tubs are generally preferred. The construction differs somewhat from that described in either of the foregoing paragraphs. In Figs. 382 and 383 a representation is given of a form of tub common in the metalliferous mines of that country. It is the old German *Hund*, or "dog-sledge," mounted upon wheels suitable for running upon rails. It consists of a rectangular box or body supported upon two fixed axles, the wheels being on the outside of the body. The weight of this tub is about 4 cwt., and its capacity for coal about 12 cwt.

An improved form of tub from the same districts is shown in Figs. 384 and 385. The sides of the body are curved to increase the carrying capacity, and the wheels are set beneath the body to enable it to run in narrow ways. The upper edges are bound with iron straps, and in each of the upper angles there is a stout iron eye. The use of the latter is to allow the tub to be attached directly, by means of four short chains, to the drawing rope in narrow shafts. The wheels in this, as in the "hund-tub," are loose. The weight is about $4\frac{1}{2}$ cwt., and the capacity, measured for coal, about $6\frac{1}{2}$ cwt. It will be observed that this tub is strongly built.

Figs. 386 and 387 represent a German coal waggon, used chiefly for the transport of coal at surface. The body is of the pyramidal form, and is strongly bound at the angles and the upper edges with iron straps. It is set upon a stout wooden framing, the sides of which are prolonged to form buffers. The wheels are set beneath the body and are fixed to the axles. Two of the wheels are provided with a brake. The weight of this waggon is about 9 cwt., and its carrying capacity about 16 cwt.

A coal waggon similar to the foregoing, but of lighter construction, is shown in Figs. 388 and 389. In this, the framing is reduced and the buffers omitted. The same form is preserved in the body, but the wheels are made to run loose upon the axles. A modified form of brake is also applied. The weight of this tub is about 8 cwt., while its carrying capacity is the same as that of the tub last described, namely, about 16 cwt. An examination of the design and construction of these tubs relatively to the requirements of practice already discussed, will show that they have not received that attentive consideration which has led to the forms of French and Belgian tubs previously described.

The tub in common use in the Californian mines is shown in Figs. 390 and 391. It is made of wood, and has a capacity of 16 cwt. The body is made of plank from $1\frac{1}{2}$ to 2 inches thick, lined with sheet iron, and strengthened with iron bands on the outside. The inside dimensions are 3 feet 10 inches long, 2 feet broad, and 2 feet 4 inches deep. The trunk or framing upon which it is supported consists of a strong rectangular frame, the two longitudinal pieces of which have their front ends bevelled off, to allow of the body being "dumped" or tipped. A cross timber near the middle of the framing supports the body, and an iron pin attached to the bottom of the body passes through the latter, and serves as a pivot on which it may be turned to either side and tipped. Another cross timber on the framing supports the hinder end of the body. The wheels are of cast iron, and turn loose on the axles. The diameter of the wheels is 12 inches. A little cap may be screwed on to the wheel over the end of the axle, to retain the lubricating oil and to exclude dirt. The wheels, it will be observed from the drawings, are beneath the body. The front end of the

body is hinged at the top, to swing as a door for the discharge of the contents. It is closed by a button, that may be turned up to confine the door, or turned down to release it; the button is fixed on an iron rod passing under the body to the back end, and is controlled by the man who pushes the tub before him. An iron rod at the back end of the tub, which, when adjusted for that purpose, serves to prevent the body from swinging on its pivot, is so connected with the rod on which the button is fixed that the door of the tub may be opened, and body made free to swing to either side by one and the same movement on the part of the man in charge. The weight of this tub is about 4 cwt.

Tipping tubs, tipping or teeming waggons, or tipplers, are extensively used in some mining operations. A simple form of tipping waggon is shown in Figs. 392 and 393. The fore part of the body is made sloping to facilitate the discharge of the contents, and means are provided whereby the body may be readily tipped forward. The arrangements for tipping will be clearly seen in the drawings. The weight of this waggon for a carrying capacity of 16 cwt. of coal, is about 8 cwt.; and for a capacity of 8 cwt., about 5 cwt.

A more complex form of the same waggon is shown in Figs. 394 and 395. The body is the same as that just described, but it is supported upon the framing carried by the wheels in a manner that allows of the body being tipped in any direction. Under some circumstances, the advantage thus obtained is of considerable importance. The additional parts required in the construction of this waggon increase its weight by an amount varying from $\frac{3}{4}$ cwt. to 1 cwt., according to the carrying capacity of the body. The weight is about the same whether the body be constructed wholly of iron, or of wood strongly bound with iron, and supported by bolts.

Another form of tipping waggon is shown in Figs. 396 and 397. In this, one side of the body is made sloping, and means are provided for tipping in that direction. In other respects, the construction of the body is the same as in the two waggons last described. It will, however, be observed from the drawings that the framing upon which the body is carried is very differently constructed. The carrying capacity of the side tippler is the same as that of the forward tippler just described, and the weight is also about the same. This waggon may be constructed to tip to either side, as may be required, the additional weight of the extra parts needed in such a case being from $\frac{1}{2}$ cwt. to 1 cwt., according to the capacity.

Figs. 398 and 399 show a tipping waggon provided with a door. The body is rectangular, and constructed of wood, the angles and the upper edges being bound with iron. The door is hinged upon an iron bar, and is hung to open upwards. The framing upon which the body is supported is of iron, and the mode of support is such as will allow of the body being turned and tipped in any direction. Sometimes a wooden framing is adopted. The carrying capacity of this waggon is about 16 cwt. of coal, and its weight about 11 cwt.

Tipping Cradles.—In order to quickly empty tubs of their contents on reaching the surface, apparatus are made use of, by means of which the tub may be tipped. These apparatus are known as "tipping," "teeming," or "dumping cradles." Some of those erected at the pit bank are of very simple construction; others are of more elaborate design. In Figs. 400 and 401 will be found a representation of a tipping cradle, commonly used on the platforms at the pit mouth of collieries. The construction needs no description, as it is clearly shown in the drawings. The loaded tub is run into the cradle, and the latter is quickly tilted into the position necessary to allow the contents of the tub to run out. The cradle is then as readily turned back into its first position, and the empty tub

run out. Several tipping cradles are required at the pit mouth of extensive collieries. The tubs are run up to them upon rails, or upon a flat surface covered with boiler plate. In the latter case, guides are used to direct the tub upon the cradles.

Another kind of tipping cradle is shown in Fig. 402. It consists of two side discs fixed upon iron arms radiating from the axle, and connected at the top and the bottom by bars of angle iron. Upon the latter are fixed the rails upon which the tub is run into the cradle. These rails are also of angle iron. A pinion is fixed upon the axle at one side of the cradle, and an endless screw turned by a winch handle gears into the pinion. The loaded tub being run into the cradle, the winch handle, which is supported by a vertical iron pillar, is turned by the man in charge until a sufficient inclination is given to the rails upon which the tub rests to cause the contents of the latter to be discharged. A few backward turns of the handle then restores the tub to the horizontal position, and it is run out to make room for the next, which, at a lively pit's mouth, has by that time arrived.

In the cradle last described, the tub is tipped endwise; but sometimes it is desired to discharge the contents over the side of the tub. To allow this to be done, the construction is modified as shown in Fig. 403. In this, the rails are laid from end to end, and the tub is run into the cradle through the opening left for that purpose. As this opening renders a central or axial support impossible, that end of the cradle is made to rest upon friction wheels, as shown in the drawing. Over the tub is set a kind of shield to prevent the contents of the tub from being scattered. It will be obvious from the drawing that the tub may be tipped to either side. The means for tilting the cradle are the same as in Fig. 402.

Junctions and Turntables.—The underground roads of a mine frequently intersect each other at a great angle, in numerous cases perpendicularly. Under such conditions, upon a common railway, the junction is effected by means of a turntable; but upon underground lines its cost and somewhat complicated construction render its use impracticable by reason of the great number that would be required, and the frequent occasion for its employment. The means adopted, however, are similar in principle, though the details have been varied to obviate the disadvantages alluded to. They may be said to consist of a fixed table, upon which the tubs are turned by being lifted at one end and carried, or by being dragged round by the men or boys in charge of them. This table or platform is constructed of stout planking, carefully laid, and usually covered with iron plates, to diminish the friction and to lessen the wear and tear. The construction may be varied to suit the requirements of the case; but it will always be of a very simple character. The chief points demanding attention are to lay the floor evenly, and to give the structure sufficient stability to bear the somewhat violent strains thrown upon it. The ends of the rails are brought upon the flooring and made to curve outwards, and between these curved portions, ribs, or raised guides, curved in the contrary direction and brought together at a point, are placed; the object of this arrangement is to facilitate the entrance of the tubs. Fig. 404 represents a junction at right angles of two branch lines with one of the secondary main lines, and shows the application of the system to such a case. The whole of the arrangements will be readily understood from this drawing. It will be observed that the space in the centre is left clear to allow the tub to be turned round and directed as required. If the same direction is to be continued, the tub is simply drawn or pushed across the floor. Sometimes a circular rib or guide is placed in the middle of the floor, as shown in Fig. 405. The diameter of this guide is slightly less than the gauge of the line, the object of the arrangement being to keep the tub in the middle of the floor, and thus opposite the entrance to each of the lines, while it is

being turned round. The system is applicable to the junction of the lesser roads, the pass-bys, and the points where trains of tubs are made up and distributed. It will be observed that it is unfavourable to the use of fixed wheels.

At some of the more important intersections of the secondary with the main lines, it becomes desirable to use a turntable. At these important points and also at some points at surface, the system just described would necessitate much labour, and would, moreover, cause great wear and tear to the tubs, and occasion delay in transit. The tables used at these points have lately been much simplified in construction and consequently cheapened. For this reason, it is to be hoped that they will be more extensively adopted in the future, even at those points where the fixed table or floor has been considered sufficient. Fig. 406 shows one of these tables. The construction and action are so clearly shown in the drawing that no description is needed. It will be observed that the arrangements are similar to those of the fixed platform. Fig. 407 shows a somewhat different mode of construction. In this, the central circular guide is used.

Sheaves and Pulleys.—Besides the sheaves or winding drums which are driven directly by the winding and hauling engines, and which will be treated of later, other sheaves, reels, and pulleys are required for the purposes of underground haulage. At the top of a self-acting plane, a reel or drum is needed to hold the rope or the chain by which the full tubs are lowered and the empty ones raised. Wherever such a system of haulage is adopted as those known respectively as the "tail-rope," the "endless-rope," and the "endless-chain" systems, several sheaves may be required, and numerous pulleys at the angles and curves in the roads. The uses of these will be pointed out as they are described. The construction of such sheaves and pulleys is very simple, and it may be assumed that it is shown with sufficient clearness in the drawings to render a full explanation unnecessary.

A sheave, reel, or drum, upon which is set a brake to control its motion, is the only mechanism required to work a self-acting plane. The apparatus may be made to revolve about either a vertical or a horizontal axis; the latter arrangement being the more common. In the former case, only one rope is used, which is passed round the sheave, one end being attached to a tub at the bottom of the plane, and the other end to a tub at the top of the plane. In the latter case, either two ropes coiling in contrary directions may be used, or a single rope sufficiently long to be passed several times round the reel. In some instances, an endless rope has been employed, which is made to pass over a pulley at the bottom of the incline, and kept in a state of sufficient tension by means of a counterweight connected to the pulley. With the endless rope, the tubs are required to succeed each other with great regularity; the full tubs descend on one line of rails and the empty ones ascend on the other. Whatever the arrangement adopted may be, a powerful brake must always be provided. This brake may be of very simple construction, consisting merely of a segment of wood fixed to a lever, and arranged to be readily brought into contact with the periphery of the sheave. To obtain greater power, compound levers may be employed, and the same object may be attained by means of an iron band enclosing the whole of the periphery and worked by a system of jointed levers. The mode of applying a brake is a matter of some importance. It is evident that the brake may be so arranged that when left to itself it shall be in operation, or the arrangement may be such that the brake shall cease to act when left to itself. In the former case, the force is applied by means of a weight attached to the end of the lever; in the latter, the force is applied by hand. The former method of

arranging the brake is generally the best to adopt, as it offers the greatest security against the negligence of the brakesman. It is well to adopt the principle that the apparatus of a self-acting plane should be incapable of setting itself in motion without the intervention of the brakesman. The latter, to start the tubs, releases the brake, and holds it wholly or partially released during the time of the descent of the load. In this way, he is able to regulate the motion, and to arrest it easily at the proper moment.

In order that the brake may be capable of controlling the motion of the load, as well as that of the sheave or reel, it is necessary to arrange the rope in such a way that it cannot slip. With the horizontal reel, this may easily be effected by passing the rope a few times round it: three or four times being abundantly sufficient. But with a sheave turning about an axis that is perpendicular to the plane, this expedient cannot be so readily adopted. One turn round a sheave having the ordinary kind of groove would be insufficient to prevent slipping. In such a case, the groove may be made conical, so as to grip the rope, or one of Fowler's clip pulleys may be used. Another method consists in passing the rope several times round the sheave, and providing an arrangement by which the friction of the several turns of the rope against each other is avoided. The arrangement is merely the addition of one or more parallel grooves to the sheave, which is then put in relation with another sheave, of any diameter, provided with one groove less. The rope is wound and unwound upon this sheave regularly, as upon one of the ordinary kind. A diagrammatic representation of this arrangement is shown in Figs. 408 and 409.

The friction of the rope upon a self-acting plane is, it may be remarked, considerable; and as this friction not only absorbs the motive power, but causes a rapid wear of the rope, it is very important that it should be reduced as much as possible. This is accomplished by means of friction rollers, placed at sufficiently short intervals apart throughout the plane to prevent the sag of the rope from causing contact with the ground. These friction rollers should be of a considerable diameter relatively to their gudgeons, which should be kept well greased, for otherwise they will not turn, but constitute fixed points of support to the rope. Two forms of friction rollers, with the method of fixing them, are shown in Figs. 410 to 412. The latter form is used on those portions of the road where the rope has a tendency to oscillate.

The reels and sheaves used upon self-acting planes should be of a simple character, and fixed in a manner that renders them capable of being easily shifted from point to point as the workings progress. Common forms are shown in Figs. 413 to 415. In the former of these, a sheave is fixed in the middle, upon which the brake acts. The reel turns in bearings fixed upon two props securely set in the roof and floor rock, and the posterior end of the brake may be fixed upon a prop, or in any other manner that may seem more suitable. The other end of the brake will be handled by the brakesman; or by compounding the leverage, as shown in the drawings, will be connected to a second smaller iron lever, an arrangement that gives greater control of the apparatus. The segment embracing a portion of the circumference of the sheave is bolted on to the lever, so as to allow of its being readily replaced by a new one when it is worn out. Soft wood should be used for these blocks. In Fig. 415 the sheave, which is provided with a conical or V groove, has its axis perpendicular to the plane. The rope in this case passes once round the sheave, upon which a brake may be made to press by any convenient arrangement. The wooden framing carrying the sheave is fixed down to the floor by means of stout iron cramps, driven into holes bored in the rock. An apparatus of this nature, like the preceding, may be quickly removed to a higher point, as the

workings progress: this is a quality of considerable importance in such apparatus, which has frequently—sometimes every two or three days—to be shifted higher up the plane. When the inclination becomes great, Fowler's clip pulley, with which a single turn of the rope will be sufficient, may be used. This pulley, represented in Fig. 416, is constructed to grip the rope with a force proportionate to the tension upon it—an object which is completely attained by the mechanism shown in the drawing.

Sheaves are required to lead the ropes and chains round curves in the several systems of haulage adopted on underground roads. In Fig. 417 is shown a sheave for carrying the rope at such points for the tail-rope system. It is usually set, as shown in the drawings, in walling built for the purpose. The construction is of a very simple character.

In the endless-rope system, it becomes necessary to keep the rope very tight, as otherwise it is liable to slip. This is effected by the arrangement shown in Fig. 418. It consists of a carriage running on wheels, to the hinder end of which a chain is affixed. This chain passes over a pulley and down a pit or staple, the lower end being weighted. The weight descends as the rope stretches, and in that way keeps the latter at the same tension. The weight used is about 15 cwt. Another form of tightening pulley is shown in Fig. 419. The pulley is fixed upon a strong timber frame to which a screw is attached. The screw is secured by a chain to a balk of timber set nearly vertical, as shown in the drawing. The rope is kept tight by turning the screw as occasion requires.

Connections.—Among the means of connecting the tubs to the ropes and chains used in haulage, the following merit attention :

Fig. 420 shows the connection used between the set of tubs and the rope in the tail-rope system. It consists of a knock-off link secured by a cottar. When the cottar is removed, the link is pushed off by the foot. Another mode of connection is shown in Fig. 421. The main rope is attached to the sets by fastening the shackle, which is on the end of the chain, to the coupling chain of the end tub, with a pin which is secured in its position by a spring cottar. The tail rope is attached by placing the end link of the chain in the centre bar, and securing it by a pin which is fixed to the end of the tub, as shown in the drawing. Fig. 422 represents yet another kind of link used for these connections. The mode of securing and loosening this link is clearly represented.

A means of connecting the tubs to the rope in the endless-rope system of haulage is shown in Fig. 423. It consists of a chain 6 feet in length, having a hook at each end. This chain, having been connected to the coupling chain of the tub, is thrown over the rope, which is constantly in motion. It is passed twice over the rope, the hand being introduced under the rope to receive the coils, in order to let the chain slide loosely on the moving rope till the hook is secured. When the two coils have been passed over the hand, the latter is withdrawn, the point A is brought over the hook, and the chain is pulled tight. When the weight of the tub comes upon the chain, the coils are drawn close together, and they form a very secure fastening. An expert hooker-on does not need to put his hand between the coils; but he simply passes the chain round the rope, and secures it before the rope has had time to move on. Both the fore and the hinder chains are attached in the same manner.

Another connection of a similar nature is shown in Fig. 424. Instead of the connecting chains being passed round the rope, strong loops of hemp are fastened on to the rope by a wrapping of string, at regular distances apart. One hook of the chain is first attached to the tub, and the hook at the

other end is then passed through the loop, as shown in the drawing. The loops are of hemp, one inch in diameter, and are strong enough to draw ten or twelve tubs at a time up a considerable incline. Less labour is required to make the connection in this way than in that last described.

In some cases, the rope runs along upon the floor of the waggon way, beneath the tubs. A kind of clamp is then used to make the connection between the rope and the set of tubs. Two of these clamps are shown in Figs. 425 to 429. The construction and mode of action of these clamps will be readily understood from the drawings. The clamp being closed by the lever handle and held by a pin, or by means of the link, the rope is firmly gripped. The set of tubs is connected to the clamp by a short piece of chain. Such clamps are worked by a man who rides in the first tub at the front end of set.

Cages.—It was formerly the custom to tip the coal as it arrived at the shaft, into vessels of various forms, in which it was raised to bank. This vessel, being allowed to swing loose in the shaft, rendered it impossible to wind at a high speed. Moreover, it was necessary to adopt some arrangement whereby the ascending vessel was prevented from coming into contact with the descending one, when two were used in the same shaft. This system of winding was very slow and insecure, and in consequence of the jolting occasioned by the vessel striking against the sides of the shaft, both it and the rope were speedily destroyed. Another disadvantage of this system was the delay and the injury to the coal occasioned by tipping it into the vessel at the bottom of the shaft, and by tipping it out again at surface. The system is still in use in Belgium, where the vessel in which the coal is raised is called *cuffat*, and partially in Staffordshire, where the coal is raised upon skips to be hereafter described. The necessity for raising a large quantity of mineral in a given time, for obtaining that quantity in a better condition, and for providing a system of winding more secure to life and limb, led to the adoption of cages moving between guides. These so-called cages are iron constructions, made to contain one or two or more tubs, which are in this way raised through the shaft with their contents. The tub is run on to the floor of the cage at the bottom of the shaft, and off again when the cage has arrived at surface. Thus the objections to the transfer of the load from one receptacle to another are altogether obviated. Also, as the cages are made to run between guides, they may be raised and lowered at a high speed with perfect safety. In some pits, the load is raised with a velocity of 20 feet a second. The introduction of the cage which is due to Mr. Curr, of Sheffield, must be regarded as the greatest improvement ever effected in the operation of winding. One serious disadvantage attending this system is the great increase of the dead weight to be raised in the shaft. But this disadvantage is much more than compensated by the gain in the directions already pointed out. This additional dead weight remains, however, an important matter to be dealt with by mining engineers, the question being how to reduce this weight to a minimum.

Cages are merely receptacles for the tubs, or vehicles in which the loaded tubs are transported to surface and the empty tubs returned from surface to the workings. Their use being merely to travel up and down the shaft, they are not subject to any of the conditions which determine the construction of the ordinary rolling stock. But the conditions prevailing in this case become obvious on reflection. Thus it is clearly apparent that the requirements of a drawing cage are: 1, that its form and capacity shall be such as will allow a sufficient number of tubs to be readily placed in it and removed from it; 2, that its form and mode of construction shall be such as will allow it to run easily along its guided path in the shaft; and 3, that its mode of construction and material shall be such as will allow the greatest carrying capacity with the least weight of cage.

It will be seen that the form of a drawing cage is determined, first, by the division in the shaft in which it has to travel; and second, by that of the tubs which it has to contain. Those divisions are always rectangular, and the tubs, as already shown, possess the same form. Hence it has happened that the rectangular form has been universally adopted for the drawing cage. Its capacity is determined chiefly by the requirements of the output. In many cases, it has but one floor, and is then described as "single-decked." This floor may be constructed to carry either one tub, or, what is a more frequent arrangement, two tubs standing end to end. The floor is laid with rails, to facilitate the introduction and withdrawal of the tubs. To keep the latter in their position during their transit to surface, or from surface to the shaft bottom, some kind of catch is used, often a simple latch which, when hanging vertically of its own weight, projects over the opening into the cage. This opening is left in both of the shorter sides of the rectangle, in order that the loaded tubs may be pulled off on one side, and the empty tubs pushed on on the other. In the two, three, and four-decked cages we have merely a repetition of this floor at different levels. The top of the cage is provided with an iron bonnet or roof for the protection of persons riding in the cage. In the middle of the shorter sides are fixed the guide cheeks, when rigid wooden or iron conductors are used. With the flexible wire-rope conductors, rings are provided at each of the angles. The cage is suspended from the rope by four short chains at each of the upper corners, and, in the case of heavy cages, from the middle of the larger sides as well.

Drawing cages are generally constructed of wrought iron, and, as a wide margin of strength must be allowed, the parts are necessarily excessive in section, and strongly put together. These conditions make the dead weight of the cage great, and it is sought, by adopting suitable forms of section and modes of assemblage, to reduce this weight to the lowest practicable limits. As at present constructed, wrought-iron cages weigh from 5 to 6 cwt. when designed to carry a single tub, and from 9 to 10 cwt. when the carrying capacity is two tubs, whether the cage be a single or a two-decker. A two-decker cage, constructed to carry four tubs, may weigh from a ton to a ton and a quarter, or even more. Thus it will be seen that the dead weight of the drawing cage constitutes a very important item in the load to be raised. Recently successful attempts have been made to reduce this dead weight by substituting steel for wrought iron, and it is probable that this material will ultimately be generally adopted. The cost of drawing cages varies, of course, with the price of iron; but, taking an average, it may be said to range from about 35*l.* a ton for wrought iron, to about 45*l.* a ton for steel. The construction of these cages is shown in Figs. 430 to 436. The design shown in Figs. 430 and 431 is for a wrought-iron single-decked cage to hold two tubs; that shown in Figs. 432 and 433 is for a steel two-decked cage to contain four tubs; and that represented in Figs. 434 to 436 is for a steel two-decked cage to carry two tubs, and to be used with wire-rope conductors.

In Staffordshire, a system of winding still prevails similar in character to that of the corves generally in use in former times. Instead of using cages in which to raise the receptacles containing the coal, these receptacles are themselves suspended directly from the rope, and raised in that manner in the shaft. They differ also entirely in their construction from tubs, being composed, as shown in Fig. 437, of a platform carried upon wheels, and of two or three large iron hoops. To load these "skips," as they are called, a quantity of coal is stacked upon the platform, and the largest hoop is then placed over it to keep it in position. A second quantity is then stacked up, and a second hoop of a somewhat smaller diameter placed over it. These operations are repeated with hoops of smaller

size, until the pyramid of coal has attained the limit of height allowed. The mass is further held together by the four chains by which the skip is suspended from the drawing chain. The load is then drawn by a horse to the bottom of the shaft, where it is attached to the drawing chain. On arriving at surface, it is simply drawn by the banksman from over the shaft mouth by means of a hook, and lowered upon the landing, or he pushes a platform over the mouth of the shaft beneath the load, upon which platform the load is then lowered. The loaded skip having been run off, and its place supplied by an empty one, the latter is raised sufficiently to allow the platform to be withdrawn and then lowered into the shaft. In this system, the winding is necessarily slow.

The drawing cages used in the Californian mines are similar in design to those already described. One of these is shown in Figs. 438 and 439. The bottom of the cage is a simple platform, 5 or 6 feet square, according to the size of the compartment, formed of wrought-iron bars firmly joined together and covered by a floor of wood, provided with pieces of track iron on which to receive the car. The two sides of the cage, above the platform, which are next the guides in the shaft, are formed of a simple but stout framework of iron, 7 or 8 feet high, joined at the top by a central cross-bar connecting them, above which is a stem or vertical rod of iron, by means of which the whole is attached to the hoisting cable. The two sides of the cage between the frames are open, for the admission or exit of the car, men, or material with which the cage is loaded.

The cage is guided in its movements in the shaft by two vertical strips of wood, or guide rods, 4 inches by 6 inches in size, attached to the lining of the shaft, one on each side of the cage, and extending from the surface to the bottom.

Attached to the cage on each side, near the top and bottom, are iron flanges, commonly called "ears," so made as to embrace the wooden guide-rods already referred to.

The mode of construction of these flanges is very simple, and may be easily understood by reference to the figure. The wooden guide-rods are in general use, and have replaced those of iron that were formerly employed in some places. They are better adapted to the action of the "safety catches" described in the following paragraph, and permit an easier movement of the cage, while allowing sufficient play to prevent the cage from binding or sticking fast, an accident which is sometimes liable to occur whenever the shaft or the guides are a little out of line, and which is likely to be followed by serious consequences.

Some of the cages in general use are constructed as simply as possible, with the only end in view of providing a suitable platform for the support and transportation of the car or other load. Others are constructed with various appliances to ensure safety, so that in case the cable or winding apparatus should break, the progress of the cage may be arrested wherever it may be at the moment of the accident, and so preserved from falling to the bottom with its load. The various devices applied for this purpose to these "safety cages" differ a good deal in detail of construction, and probably in degree of efficiency; but they generally depend on a spring so fixed, with regard to the rod by which the cage is attached to the cable, as to be compressed while the weight of the cage exerts any strain upon the cable, but if that strain is relaxed by the breaking of the cable or other parts of the winding machinery, the spring is permitted to act upon some mechanical contrivance, by means of which stout iron teeth are forcibly projected against, or caused to grasp, the guides along which the cage is moved. The teeth are so arranged, that when the spring is compressed they move along the guide without coming into contact with it; but when the spring is relieved, act with the greater force the heavier the load on the cage.

One of these contrivances may be seen in Figs. 438 and 439. A horizontal movable bar of iron crosses the cage near the top, from side to side. The lifting rod *r*, by which the cage is attached to the cable, passes through this bar, and is so connected with it that the latter may move upward and downward between guides *g g*, according as the rod is raised or suffered to fall. When the rod is raised by the strain of the cage on the cable, the bar is elevated; but if the strain on the cable is relaxed, the rod consequently falling, the bar moves downward, and a strong spring is introduced to force it down whenever this condition occurs. To each end of this cross-bar, on opposite sides of the cage, is attached at right angles a shorter horizontal bar, Fig. 439. To each extremity of each of these last-named bars is attached one end of a system of levers, by means of which two stout iron teeth or "dogs," *t t*, at the other end are thrown against the guide rods in the shaft when the cross-bar is down, or drawn from the guide rods when the cross-bar is raised.

In Fig. 439 this contrivance is shown in such manner that the action of the levers can be readily traced. The cage not being suspended by the cable, the cross-bar is depressed, and the teeth are almost in contact with each other, in the position in which they would grasp the wooden guide-rods were the cage in the shaft without its usual support. The dotted lines indicate the position of the levers and teeth when the cage is hanging on the cable and the cross-bar *b* is raised.

This kind of safety catch has been proved to be very efficient. On one occasion at the Savage Mine a cage was descending at usual speed, with thirteen men, when by a singular accident the cable became detached from the lifting rod of the cage. The latter stopped almost immediately, but with so little shock that the men on the cage were not even led to suppose that an accident had happened. The engine-man, not perceiving any difficulty, continued to unwind the cable, which, passing down between the cage and the side of the shaft, attracted the attention of the men, who rang to stop. Another cage was sent down in the adjoining compartment, when the state of the case was discovered and the men relieved.

Another appliance for ensuring safety, more common, and by some preferred to the one just described, is that known as the "Eccentric." This is illustrated in Figs. 440 to 442. The general form of the cage may be the same as in the case already described. The contrivance for ensuring safety consists in two round shafts, or rods, *a a*, which extend across the cage from side to side, parallel to the central cross-bar, *b*, of the main frame. They are supported by the main frame of the cage in such manner that they may revolve freely, and they extend beyond the sides of the cage so that their ends are opposite the wooden guide-rods *c c*, of the hoisting shaft. To each end of these two rods are attached the eccentrics, *a a*, which are circular pieces of cast iron, supported, as their name implies, in such manner that the centre of the shaft *a*, or axis of revolution, does not coincide with the centre of the circle. That part of the circumference of the circle which is nearest to the point of support is smooth, but that which is more remote is furnished with teeth, so that when the shafts *a a* are in such position that the smaller diameter of the eccentrics is turned towards the guides, they may move freely, up or down, without coming into contact with the guides; but if the shafts *a a* be turned so as to present the larger diameter of the eccentrics to the guides, the latter are grasped by the teeth just referred to. Each eccentric rod is furnished with a chain *e*, one end of which is fixed to the rod, and, winding round it, is attached at the other end to a bolt, which passes through the cross-bar *b*. Between the head of the bolt and the cross-bar a strong steel spring, *f*, is interposed, the tendency of which when compressed is to cause the shaft *a* to revolve in such manner as to bring the teeth of the eccentrics into contact with the guides. The chains, *g g*, by which the

cage is supported are fixed at one end to the upper part of the lifting rod *h*, while the other end passes around the shaft *a*, as seen at *i* in Fig. 441, and is attached to it so that the tendency of this chain, while there is any strain on the cable, is to turn the shaft *a* in such manner that the eccentric teeth are moved away from the guides. If, however, by the breaking of the cable or other reason this strain be relaxed, the springs *f f* act upon the shaft *a*, and turn the eccentric teeth towards the guides, thus preventing the fall of the cage. This movement is assisted by the spring *j*, which is interposed between the bottom of the lifting rod *h*, and the ring R, through which the rod passes.

This kind of safety attachment has been repeatedly tested by accidents, which, but for the efficiency of the contrivance, would have proved fatal to life. The cage is sometimes furnished with a hood or covering of iron, usually made of boiler-plate, for the purpose of protecting the men from the danger of the cable, if broken, or other bodies falling in the shaft. Such a hood is shown in the drawings. It is usually, though not in the case illustrated, hinged in the middle, so that the two sides may be turned up when it is desired to send down long timbers on the cage. The necessity, for other reasons, of having the hood made in two hinged parts was shown by an occurrence in the Gould and Curry Mine some time since, when two men who were being lowered to the bottom of the mine found themselves descending below the surface of the water, which had risen higher than they had supposed. They endeavoured to climb upward, but the hood not being a hinged one they were securely imprisoned in the cage. Fortunately a signal reached the engine-man in time to save them from drowning. Iron hoods underneath the hook serve to keep it securely closed when so desired.

Keeps.—When the cage has been raised to the mouth of the shaft, some means are needed for supporting it in that position. These means usually consist of a system of levers called, from their use, "keeps," which are raised by the cage as it ascends, and which, by being weighted, drop back into their positions as soon as the cage has passed. With this arrangement, the cage is drawn up sufficiently far above the shaft mouth to allow the keeps to fall back into their position, in which their extremities project slightly over the shaft, and then lowered upon these projecting keeps, which are incapable of further downward motion. The cage rests upon these keeps while the loaded tubs are being run off and the empty tubs run on. When these operations are finished, the cage is again raised out of the way of the keeps, which are drawn back by the lander, and held by him clear of the shaft until the cage has descended below them. For this purpose, they are connected to a lever, and worked after the manner of a railway switch. In some instances, the levers are arranged to be worked by the foot. It is obvious that a system of keeps may be contrived in a variety of ways, so that it is wholly unnecessary to describe any one in particular. Simplicity of construction and strength of parts are the only essential conditions to be satisfied in a design of this nature. It may be remarked here that when the cage is two-decked, the operations of raising and lowering upon the keeps have to be repeated for the second level, and that the arrangements at the bottom of the shaft are similar to those at the top. To avoid this repetition, however, the arrangements sometimes include a staging by means of which the loading and the unloading of the cages may be carried on at the different levels at once. This is notably the case in Belgium, where four-decked cages are not uncommon.

With such an arrangement, and a two-decked cage, when the lower deck of the cage at surface is on a level with the shaft mouth, the upper deck of the cage at the bottom of the shaft is on a level with the floor of the roads entering the shaft; the lower deck is here reached by means of an

inclined plane. When the cage is single-decked, the arrangements of the on-setting and the landing places, as well as the operations of loading and unloading, are greatly simplified.

One arrangement of these keeps is shown in Fig. 443. They consist, it will be observed, of four tappets, two on each side of the shaft, just below the floor. They are fixed upon a light iron shaft which may be partly revolved, turning the tappets upward entirely out of the path of the cage when the latter is to be lowered. The cage, in ascending, striking the tappets, raises them in passing, when they fall again into place, and the cage is lowered upon them. When the cage is ready to descend again, it is first raised a few inches, the tappets are turned up out of the way by means of a lever within reach of the lander, or man who attends to the car, and held in that position until the cage has passed down. This contrivance is illustrated in the drawing, which represents a section of the mouth of the shaft and of the platform of the cage, taken through the line *i i* of Fig. 438. P is the platform of the cage, and *p p* are the cross-bars of the frame, to which the tappets *h h* afford support when in the position shown in the drawing. The tappets are fixed on light round shafts below the floor, and may be turned slightly toward or from the cage by means of levers, one end of which, the handle L, is within reach of the attendant, and the action of which may be readily understood by an inspection of the drawing. The dotted lines indicate the position of the various parts of this contrivance when the lever T is drawn back, so as to turn the tappets out of the way of the descending cage. By this movement the springs *j j* are forced into the position indicated by dotted lines, and cause the tappets to return to their former place as soon as the lever T is released by the attendant. A similar arrangement is sometimes employed at the different stations in the shaft, though usually, when hoisting is in progress from any particular station, it is common to place a few planks across the shaft for the cage to rest upon.

The waggon, while on the cage platform, is held securely in place, sometimes by hooks fitting into staples in the body of the car, sometimes by tappets, which, being fixed under the platform, may be turned up so as to block the wheels of the car, or turned down again to permit its exit. These blocks are controlled by handles, *k k*, on the sides of the cage, as may be seen in the drawings. It will be observed that the handles not only extend in opposite directions, but are attached to opposite sides of the cage.

Head Gear.—The head gear constitutes a very important part of the fittings of a shaft. It consists essentially of a pulley frame, constructed either of wood or of wrought iron, carrying a pulley, or more frequently two pulleys, over which the rope suspended in the shaft is passed, and led thence to the drum of the winding engine. These pulleys are provided with a round or a flat groove, according to the form of the rope used, and are made of a large diameter, in order to avoid giving a quick bend to the rope. The design and construction of these pulley frames, or head stocks, demand careful consideration, inasmuch as they are extremely important structures, and are required to fulfil various conditions. The two essential features which these structures must possess, are height and strength. It is obviously necessary to safety that the pulleys over which the ropes pass should be placed at a considerable height above the mouth of the shaft, since by this means alone can a margin of safety be allowed to the engine-man. If it be borne in mind, that with the winding drums of large diameter now in use, a single stroke of the engine is sufficient to raise the cage 50 or 60 feet in the shaft, the necessity for such a margin will be apparent. For this reason, the height of pulley frames is made to vary from 30 to 60 feet, according to the speed of winding. The security of human life, however, demands that in all cases the greater rather than the

lesser height should be approached. The condition of strength in the pulley frame is equally or even more important, since it is evident that a yielding of this structure must inevitably lead to disastrous consequences. The necessity for a great height renders this condition difficult of fulfilment, since height in any structure is opposed to its stability.

Hence arises the importance of carefully and fully considering the character and the directions of the strains to which the pulley frame is subjected, and of so designing and constructing it that it may possess ample strength to resist them. The subject is one of very great importance, and it is desirable therefore to investigate it briefly in this place. The essential parts of a pit-head frame are the legs or uprights, upon which the pulleys rest, and the spurs, or inclined supports, which are set on the side of the legs next the engine. All other parts of the frame are auxiliary to these, or to some other appendage of the frame. The uprights are intended to resist the vertical strains, and the spurs the oblique strains which tend to overthrow the former in the direction of the source of power, that is, the spurs are intended to prevent the legs carrying the pulleys from being pulled over toward the engine. Thus, in designing a pit-head frame, we have to consider these two parts relatively to the strains to be thrown upon them; and in this consideration we have, first, to determine the direction of the strains; next, the value of those strains; then the best relative position of the parts of the frame; and, lastly, the dimensions necessary to enable these parts to resist the strains thrown upon them. Each of these questions demands thoughtful attention.

The direction of the strains, as well as their value, may be readily ascertained graphically by means of the parallelogram of forces. To show the application of this method it will be well to consider some examples.

Suppose a vertical support carrying a pulley, over which a rope is passed in such a way that the two portions are parallel with each other and with the support, as shown in Fig. 444; and suppose a weight, W, attached to one portion of this rope, and a force, P, applied to the other portion, sufficient in intensity to produce equilibrium. The weight W may be assumed to be that of the cage with its contained load, and the force P that exerted by the engine.

In this case, the tension of the rope is obviously equal in both portions, since the forces are in equilibrium, and these forces are $W + w$ in one portion of the rope, and $P + w'$ in the other, w and w' being the weights of the respective portions of the rope. Now it is evident that the strain upon the support is the sum of these forces, that is, $S = W + w + P + w'$, or, if we make $W =$ the total weight, $S = 2\,W$. And it is also evident that this strain will be a vertical one, that is, it will be exerted along the axis of the support.

Suppose again that one portion of the rope is inclined to the other at an angle of 45°, as shown in Fig. 445. In this case, it is plain that the strain upon the support will be changed, both in direction and in intensity. To determine the direction and the value of the strain, lay off S A, S B equal to a unit on any scale, say 1 inch, and from the points A and B, draw A R parallel to S B, and B R parallel to S A; S A R B will then be a parallelogram, the diagonal S R of which will represent the strain, both in direction and in intensity. The value of the latter may be found by measuring the resultant S R upon the scale adopted. Such a measurement will show that when the sides of the parallelogram are equal to 1, as in the example, the diagonal representing the resultant of the forces will be 1·85. Thus, if we assume $W = 10$ tons, the value of the strain will be $10 \times 1{\cdot}85 = 18{\cdot}5$ tons, instead of $10 \times 2 = 20$ tons, as in the preceding example. If the line

S R representing the direction of the strain be produced, it will meet the ground line at the point O, and as this point is without the base of the vertical support, the latter will be pulled over in the direction of this point. Hence it becomes necessary to add a spur, and to place this spur in a favourable position to resist the strain. It will be observed that the effect of adding the spur is to widen the base of the support, and it is obvious that the greater the inclination of the spur the wider the base will be. The question now is, what, under the conditions supposed, should be the inclination of the spur? The condition of stability is satisfied so long as the resultant S R falls, when produced, within the base of the structure; hence the least inclination will be that of the line S O, which, it will be observed, is half that of the inclined portion of the rope. The angle of this portion being 45°, that of the spur will be $22\frac{1}{2}°$, and with this inclination the structure, under the conditions assumed, will be perfectly stable, since the resultant of the forces to which it is subjected will coincide with the axis of the spur. But as in practice it is possible that the force P may exceed the weight W, in consequence of some hitch occurring, as, for example, in the case of the cage being drawn up against the pulley, it is prudent to give the spur a somewhat greater inclination.

If the inclination of the rope be increased to 60°, as in Fig. 446, the strain will be again altered in direction and in intensity. Determining this strain, as before, by means of the parallelogram S A R B, we find it represented by the diagonal S R, which, being produced, will meet the ground line at O. The value of the strain S R, measured on the scale, will be found in this case to be 1·73, and, assuming the same weight as before, this value will give $10 \times 1{\cdot}73 = 17{\cdot}3$ tons. The minimum inclination of the spur will be that of the line S O, which is equal to half that of the inclined portion of the rope, or 30°.

Suppose again an extreme case, in which the two portions of the rope are at an angle of 90° with each other, as shown in Fig. 447. The strain upon the supports is represented by the resultant S R, which being produced will meet the ground line at the point O. The value of this strain, measured as before, will be found to be 1·41, which, with the same value for W, will give $10 \times 1{\cdot}41 = 14{\cdot}1$ tons, as the intensity of the strain to be resisted. In this case, the minimum inclination of the spur will be that of the line S O, or 45°, which is half that of the inclined portion of the rope. It must be borne in mind that these inclinations are measured from the vertical, and not from the horizontal.

Instead of laying off the distances S A, S B to some scale, we may merely make them equal, and then find the value of the resultant S R by calculation, from the formula $r = \frac{\sin. a}{\sin. b}$, a being the angle S A R, b the angle S R A, and r the side S R of the triangle S R A. Thus in the second example, in which the inclined portion of the rope is at an angle of 45° with the vertical portion, the value of the resultant representing the strain will be $r = \frac{\sin.\ 135°}{\sin.\ 22\frac{1}{2}°} = \frac{707}{382} = 1{\cdot}85$.

It will be seen from the foregoing considerations that the condition of stability is that the line representing the strain due to the two forces shall fall within the base of the structure, and that this base is the distance comprised between the lower ends of the uprights and of the spurs. In order to ensure that the resultant shall fall well within this base, the minimum inclination of the spurs should, as already pointed out, be slightly exceeded. In many of the pit-head frames at present in existence, the minimum inclination is greatly exceeded; but inasmuch as this circumstance reduces the strength of the spur by increasing its length, the practice is to be condemned as wrong in principle. There

is clearly nothing to be gained by increasing the base of the structure beyond the limits required by the condition of stability.

In estimating the value of the weight W, account must be taken of all the resistances that have to be overcome. Thus, at the moment of starting the engine, when the resistance is greatest, we have to consider the weight of the tubs with their contained load of mineral, which may be regarded as the useful weight, that of the cage with its attachment of chains, and also that of the drawing rope. Representing the useful weight by w, that of the cage by w', and that of the rope per yard by w'', we have $W = w \times w' \times w'' H$, H being the height in yards of the pulley above the shaft bottom. But besides these weights, it is also necessary to take account of the friction of the cheeks against the guides, and other slight resistances which may be opposed to the motion of the cage. These resistances ought not to be estimated at less than one-tenth of the total weight. This value will give us $W = 1 \cdot 1\,(w \times w' \times w'' H)$. As an illustration of the application of the foregoing, we will take a case in which the weight of the two-decker cage with its attachment is $1\frac{1}{2}$ tons, that of the four tubs with their contained loads, 3 tons, and that of the chain per yard 10 lbs., the height of the pulley above the bottom of the shaft being 400 yards. The value of W or the total weight will in such a case be

$$W = 1 \cdot 1\,(3 \times 1 \cdot 5 \times 2) = 7 \cdot 15 \text{ tons.}$$

If now we suppose that the inclined portion of the rope makes an angle of 60° with the vertical portion, and calculate the strain upon the pulley frame in the manner already described, we shall find that this value of W will give $7 \cdot 15 \times 1 \cdot 73 = 12 \cdot 37$ tons, as the intensity of that strain. Thus the structure will be subjected to a strain of $12 \cdot 37$ tons in the direction shown by the resultant of the component forces.

Having determined the direction and the value of the strains to which the pulley frame is subjected, and the inclination to be given to the spurs to ensure stability, it becomes necessary to ascertain what dimensions the parts should have to enable them to withstand these strains. The wood usually employed for pulley frames is pitch or Memel pine, and as the parts may be considered to resist after the manner of columns, we shall have to calculate the strength of that material when applied in that form. The breaking weight P for solid long square columns of dry Memel pine is $P = \frac{7 \cdot 8\,B^4}{L^2}$, B being the breadth of the side in inches, and L the length of the column in feet. As, however, the strength of timber is considerably reduced when exposed to a moist atmosphere, the coefficient $7 \cdot 8$ is too great and ought to be taken at 6. With this value the formula becomes $P = \frac{6B^4}{L^2}$, from which we deduce $B = \sqrt{\frac{P\,L^2}{6}}$. When the side of the column has this value, it will yield beneath the load or pressure P, since P here represents the breaking strain. The value of B, therefore, thus found will have to be increased according to the factor of safety determined upon. In a structure of the nature of a pulley frame, which is constantly being subjected to shocks, and which may be excessively strained in consequence of a hitch occurring during winding, the factor of safety should be taken as one-tenth, that is, the normal or ordinary strain should not exceed one-tenth the breaking strain. Arranging the formula according to this proportion, we have $B = \sqrt{\frac{P\,L^2}{0 \cdot 6}}$, in which B = the side of the square timbers which are to form the pulley frame.

In the case supposed, we have the strain equal to 12·37 tons. Substituting this value for P, and assuming the length of the spurs to be 40 feet, we have as the requisite breadth of these pieces $B = \sqrt{\frac{12 \cdot 37 \times 40^2}{0 \cdot 6}} = 13 \times 47$ inches. Thus, under the conditions assumed, the section of the spurs should be 13·47 inches square in the middle of their length. In practice, the legs or uprights are usually made equal in section to the spurs. With these dimensions we obtain a sufficient, but not a superfluous degree of strength. If it be intended to strongly brace the structure, however, the dimensions of these essential parts of the pulley frame may be slightly reduced. The systems of bracing will be described hereafter when treating of the details of constructing pit-head pulley frames. In determining the dimensions in this way, we have considered the support as consisting of only one leg and one spur. But in practice, a pulley frame is composed of two legs and two spurs, between which the load is suspended. Thus only half the load is borne by each pair of supports, and therefore the total weight must be halved in making the calculation. If $\frac{12 \cdot 37}{2} = 6 \cdot 18$ be substituted for W in the formula, we shall find the value of B to be 11·33 inches. Hence in designing a Memel pine pulley frame to support the load assumed, the principal timbers should not be less than $11\frac{5}{16}$ inches on the side in the middle of their length.

The kind of wood used in the construction of pit-head frames is usually, as before remarked, pitch or Memel pine. Though preference is generally accorded to the former, the latter will be found to be very suitable for the purpose, provided it be chosen sound and free from knots and cracks. There are various ways of arranging the several parts of a pulley frame, and also of connecting these pieces one to another; two designs slightly differing in details are shown in the accompanying drawings.

It is essential to stability that all the chief component parts of the structure should be set upon the same wooden framing by which those parts are securely held together at their bases. This wooden framing consists of sills strongly jointed and bound together, upon which the legs and spurs are set by means of cast-iron sockets bolted down to the sill. Good workmanship is an essential requisite in the construction of pulley frames, since it is important that all the joints should be accurately fitted, and the parts made to abut evenly one upon another. The double tenon joint is generally the most suitable in such structures, and it may be rendered secure by an iron bolt passing through each tenon. Over the more important joints, wrought-iron straps will be required. After the joints have been properly fitted, they should be well covered with red lead. These details of construction are shown in the drawings. The legs of the frame are slightly inclined to each other towards their summits, and are braced together. The spurs are also in some instances braced to the legs. These spurs, or back-stays as they are frequently called, are sometimes made to abut against the engine-house, instead of being set upon a sill. This practice is, however, to be strongly condemned, as being inconsistent with the requisite degree of stability. In order to obtain the greatest height possible with timber of a given length, the cap or framing carrying the pulley is placed above the uprights and back-stays, as shown in the drawings; these drawings also show the details of the construction of this portion of the framing. As it is necessary that ready access should be had to the pulley, it is usual to provide one of the back-stays with steps, whereby the top of the framing may be reached without difficulty. For the convenience and safety of the

person to whom this duty is entrusted, a hand-rail should be added; this arrangement is shown in one of the designs illustrated.

The pulleys used on pit-head frames are of iron, and they vary in diameter from 10 to 20 feet. It has already been pointed out that when wire ropes are used, the pulley must be of larger diameter, to avoid straining the metal by too sharp a bend. A common diameter is 16 feet. Formerly pit-head pulleys were constructed wholly of cast iron, and this material is still used in the South Staffordshire district, where heavy chains are employed with pulleys of small diameter. But generally this system has been abandoned for the compound system, in which the central boss and the rim are of cast iron, and the arms of wrought iron. The mode of arranging the arms is shown in the drawings. The rim of the pulley is grooved to receive the rope, and the bottom of the groove, known as the "face" of the pulley, is made either circular or flat according as round or flat ropes are to be used. It is important that the face of the pulley for flat ropes should be perfectly flat, since otherwise the rope is unduly strained. The groove in the pulley should be sufficiently broad and deep to allow the rope some degree of play. This play is desirable when flat ropes are used, to prevent any ill effects of inaccuracy in the fixing of the pulley, in consequence of which inaccuracy the vertical medial planes of the pulley and of the drum would not be perfectly coincident. But with round ropes the play is indispensable, since the rope, as it is being wound upon the drum, is constantly changing its position relatively to the vertical plane of the pulley.

The drawings illustrative of the foregoing remarks on pit-head frames, are those numbered from 448 to 460. These drawings show some of the modes of construction that may be followed, and also some of the details of forming the joints.

Wrought iron has in some instances been substituted for wood in the construction of pit-head frames, and it appears probable that this material will be extensively employed in the future. The increasing difficulty of obtaining timber of a sufficient length to meet the requirements of the present day, has, indeed, rendered the adoption of some other material than wood necessary in many cases where great height is desirable. It is evident that with an iron structure, the height is practically unlimited by the material employed; and hence we may obtain an elevation of the pulley above the mouth of the shaft of 70 or even 80 feet without difficulty. We have already pointed out the advantage of height in the pulley frame, and it is probable that these lofty structures will become more and more common as the necessity for raising a greater number of tubs at one time increases. In the construction of iron pulley-frames, the T section is generally adopted in the principal parts, and these parts are braced together by flat or by angle bars, somewhat after the manner of a lattice girder.

Ropes.—The pit rope constitutes the means through which the force developed by the engine is transmitted to the load, and is therefore an object of the first importance. The two essential requirements in a rope are flexibility and strength, and it is desirable to obtain these qualities with the least possible weight. The desirability for a light weight in the rope rests upon two different grounds. In the first place, it is important that the dead weight to be dealt with should be as little as possible; and in the second place, the strength of the rope is, in some degree, dependent upon its weight, inasmuch as the weight of the suspended portion must be subtracted from that of the useful load. Thus, if the distance between the pulley and the pit bottom be 300 yards, and the weight of the rope be 4 lbs. a yard, the strain upon that portion of the rope which is upon the pulley will be equal to

$300 \times 4 = 1200$ lbs. when the rope is unloaded. Hence its effective strength will be reduced by that amount.

In order to obtain these qualities in winding ropes most fully, various materials have from time to time been chosen, and more or less extensively adopted. Hemp was a few years ago the only material employed in the manufacture of ropes; later, aloe fibre was adopted, and these two materials are still commonly used in many places. In Belgium, aloe fibre is very generally employed. The strength of ropes made of this material is slightly greater than that of hempen ropes, and their durability is notably superior. But, on the other hand, they are heavier per unit of length, so that their superiority remains on the side of durability alone. One defect in hempen and aloe fibre ropes is their liability to absorb moisture, whereby their weight per unit of length is considerably increased. The defect is probably greater in aloe fibre than in hempen rope. More recently, iron wire has been adopted as a material for ropes, and the results have proved eminently satisfactory. These ropes consist of several wires of the toughest iron, twisted together in the same manner as the strands of the vegetable ropes, but the degree of the twist is less in the former than in the latter. Theoretically, a wire rope will best resist the strains brought to bear upon it when all the wires of which it is composed are parallel to one another; but practically, by reason of the flexibility and extensibility required, the strength of a wire drawing rope is found to be greatest when the strands are arranged spirally as in the hempen rope. In the wire rope, the weight per unit of length is, for a given strength, considerably less than in the hempen and aloe fibre ropes, and the diameter is also reduced in a like degree. The flexibility, however, is less, and, for that reason, pulleys of a larger diameter have to be employed. The transition from iron to steel was an obvious step, and hence we find the most recent ropes made of this material. The greater tensile strength of steel allows the diameter of the rope to be still further reduced, so that the weight per unit of length has again to be notably lessened. The advantages obtained by the successive changes in the material employed in the manufacture of ropes are clearly set forth in the table given hereafter.

It is desirable to point out here a change in form which has been made with a view of augmenting the effective strength, and of attaining other ends, which will be explained later. In the new form, the rope, instead of being cylindrical, is flat, and it was supposed that when arranged in this manner, the several fibres or wires of which the rope is composed would be more evenly strained than when they were all arranged spirally. This result may, however, be regarded as more than doubtful. For we have, in the first place, the fact that the fibres or wires are still arranged spirally, inasmuch as the flat rope consists merely of several small round ropes stitched together, the material forming the stitches adding to the weight, without in the smallest degree increasing the strength; and, in the second place, it does not seem probable that the separate strands are in practice more evenly loaded than they would be in the round rope. It is easy to see that even if the strain be uniformly distributed upon a new rope, that uniformity may be quickly destroyed by numerous causes. One portion of the rope may not offer the same resistance as another part, and this part, by becoming more extended than the rest, will render the strains upon the whole irregular. Also it is evident that if the face of the pulley be not perfectly flat, the rope must be irregularly strained. To prevent, as far as possible, these accidents, each strand is made as nearly as may be identical, and they are used in even numbers. Also the direction of the twist is contrary in each pair, to counteract the tendency of the twist to come out under the action of the load. In winding, the

flat rope is made to lap over itself upon the drum, so that the diameter of the latter is practically increasing or decreasing during the operation of winding. The advantages of this circumstance will be pointed out later. One obvious advantage of this overlap of the rope is, that the latter is kept constantly in the same vertical plane. The flat rope has not been regarded very favourably by mining engineers generally, and hence it has not been very widely adopted.

The quality of a rope of course greatly depends upon the method of its manufacture and the care bestowed upon the operations. It would be foreign to our purpose, however, to describe and to discuss questions of manufacture; in this place we have to deal exclusively with the application of ropes to the work of raising the produce of the mine. A primary consideration is the strength of ropes; but this is a question that can be dealt with only approximately. It has been the custom to assimilate the resistance of a wire rope to that of an iron rod of the same effective section; but it is obvious that the whole section of the rope cannot be so uniformly obtained as that of the rod. Moreover, as already remarked, the operations of manufacture introduce elements of uncertainty in the rope, which either do not exist at all in the case of the rod, or exert a much less important influence. Besides, the rupture of a wire rope is due rather to the bending strains, to which it is constantly subjected, than to the tensile strains occasioned by the load suspended from it. Hence it happens that we are compelled to have recourse to empirical methods of calculation, and to content ourselves with results of a very approximative character.

The following formulæ and table will be found practically useful in determining the dimensions of a rope of a given material required to bear a given strain. If $C =$ the circumference of the rope in inches, and $W =$ the breaking weight in tons, then for hempen ropes $W = 0 \cdot 2\ C^2$, for iron-wire ropes $W = 1 \cdot 5\ C^2$, and for steel-wire ropes $W = 2 \cdot 5\ C^2$. The safe working load may be taken at from $\frac{1}{5}$ to $\frac{1}{7}$ of the ultimate strength, according to the speed at which it is to run and the vibration to which it is to be subjected. Thus for iron-wire rope, the safe working load L will be $L = \frac{1 \cdot 5\ C^2}{5}$, $L = \frac{1 \cdot 5\ C^2}{6}$, or $L = \frac{1 \cdot 5\ C^2}{7}$, according as the speed of winding is to be moderate, high, or very high. Assuming the circumference to be 4 inches, the values of L will be $4\frac{4}{5}$ tons, 4 tons, and $3\frac{3}{5}$ tons respectively. The weight of the rope hanging over the pulley is of course included in the working load. A sufficiently close approximation to the safe working load of round wire ropes moving at high speeds may be found by multiplying the weight of the rope per fathom in pounds by five for iron wire and by eight for steel wire, the product being taken as representing hundredweights. Thus the weight of a 4-inch rope being 14 lbs. a fathom, we have $14 \times 5 = 70$ cwt., and $\times\ 14 \cdot 8 = 112$ cwt. respectively, for iron and steel wire. As before remarked, all of these results must be regarded as rough approximations, and therefore it is necessary, in determining the dimensions of a rope, to allow a wide margin of safety, which should never be less than one-fifth. Taking it generally at one-sixth, we may find the circumference of the rope by transposing the preceding formulæ in the following manner: $C = \sqrt{4\ L}$ for iron wire, and $C = \sqrt{2 \cdot 4\ L}$ for steel wire. Thus, if the working load is to be 4 tons, the requisite circumference of an iron rope will be $\sqrt{4 \times 4} = 4$ inches, and of a steel rope $\sqrt{2 \cdot 4 \times 4} = 3 \cdot 1$ inches.

The following is a comparative table of the weights and strengths of hempen and of wire ropes, as given by the manufacturers:

Flat Ropes.

Hemp.		Iron.		Steel.		Equivalent Strength.	
Size in Inches.	Weight per Fathom.	Size in Inches.	Weight per Fathom.	Size in Inches.	Weight per Fathom.	Working Load.	Breaking Load.
	lbs.		lbs.		lbs.	cwt.	tons.
$4 + 1\frac{1}{8}$	20	$2\frac{1}{4} + \frac{1}{2}$	11	..	..	44	20
$5 + 1\frac{3}{4}$	24	$2\frac{1}{2} + \frac{1}{2}$	13	..	..	52	23
$5\frac{1}{2} + 1\frac{3}{8}$	26	$2\frac{3}{4} + \frac{5}{8}$	15	..	..	60	27
$5\frac{3}{4} + 1\frac{1}{2}$	28	$3 + \frac{5}{8}$	16	$2 + \frac{1}{2}$	10	64	28
$6 + 1\frac{1}{2}$	30	$3\frac{1}{4} + \frac{5}{8}$	18	$2\frac{1}{4} + \frac{1}{2}$	11	72	32
$7 + 1\frac{7}{8}$	36	$3\frac{1}{2} + \frac{5}{8}$	20	$2\frac{1}{4} + \frac{1}{2}$	12	80	36
$8\frac{1}{4} + 2\frac{1}{8}$	40	$3\frac{3}{4} + \frac{11}{16}$	22	$2\frac{1}{2} + \frac{1}{2}$	13	88	40
$8\frac{1}{2} + 2\frac{1}{4}$	45	$4 + \frac{11}{16}$	25	$2\frac{3}{4} + \frac{3}{8}$	15	100	45
$9 + 2\frac{1}{2}$	50	$4\frac{1}{4} + \frac{3}{4}$	28	$3 + \frac{3}{8}$	16	112	50
$9\frac{1}{2} + 2\frac{3}{8}$	55	$4\frac{1}{2} + \frac{3}{4}$	32	$3\frac{1}{4} + \frac{3}{8}$	18	128	56
$10 + 2\frac{1}{2}$	60	$4\frac{5}{8} + \frac{3}{4}$	34	$3\frac{1}{2} + \frac{3}{8}$	20	136	60

Round Ropes.

Hemp.		Iron Wire.		Steel Wire.		Equivalent Strength.	
Circumference.	Weight per Fathom.	Circumference.	Weight per Fathom.	Circumference.	Weight per Fathom.	Working Load.	Breaking Load.
inches.	lbs.	inches.	lbs.	inches.	lbs.	cwt.	tons.
$2\frac{3}{4}$	2	1	1	..	..	6	2
..	..	$1\frac{1}{2}$	$1\frac{1}{2}$	1	1	9	3
$3\frac{3}{4}$	4	$1\frac{5}{8}$	2	..	..	12	4
..	..	$1\frac{3}{4}$	$2\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	15	5
$4\frac{1}{2}$	5	$1\frac{7}{8}$	3	..	..	18	6
..	..	2	$3\frac{1}{2}$	$1\frac{5}{8}$	2	21	7
$5\frac{1}{2}$	7	$2\frac{1}{8}$	4	$1\frac{3}{4}$	$2\frac{1}{2}$	24	8
..	..	$2\frac{1}{4}$	$4\frac{1}{2}$	..	..	27	9
6	9	$2\frac{3}{8}$	5	$1\frac{7}{8}$	3	30	10
..	..	$2\frac{1}{2}$	$5\frac{1}{2}$	..	..	33	11
$6\frac{1}{2}$	10	$2\frac{5}{8}$	6	2	$3\frac{1}{2}$	36	12
..	..	$2\frac{3}{4}$	$6\frac{1}{2}$	$2\frac{1}{8}$	4	39	13
7	12	$2\frac{7}{8}$	7	$2\frac{1}{4}$	$4\frac{1}{2}$	42	14
..	..	3	$7\frac{1}{2}$	..	..	45	15
$7\frac{1}{2}$	14	$3\frac{1}{8}$	8	$2\frac{3}{8}$	5	48	16
..	..	$3\frac{1}{4}$	$8\frac{1}{2}$	$2\frac{1}{2}$	..	51	17
8	16	$3\frac{3}{8}$	9	$2\frac{1}{2}$	$5\frac{1}{2}$	54	18
..	..	$3\frac{1}{2}$	10	$2\frac{5}{8}$	6	60	20
$8\frac{1}{2}$	18	$3\frac{5}{8}$	11	$2\frac{3}{4}$	$6\frac{1}{2}$	66	22
..	..	$3\frac{3}{4}$	12	..	..	72	24
$9\frac{1}{2}$	22	$3\frac{7}{8}$	13	$3\frac{1}{4}$	8	78	26
10	26	4	14	..	..	84	28
..	..	$4\frac{1}{2}$	15	$3\frac{3}{8}$	9	90	30
11	30	$4\frac{3}{8}$	16	..	..	96	32
..	..	$4\frac{1}{2}$	18	$3\frac{1}{2}$	10	108	36
12	34	$4\frac{5}{8}$	20	$3\frac{3}{4}$	12	120	40

In estimating the strains upon a rope, we must take account of that which is exerted upon it at starting. While the rope is moving at a uniform speed, the strain upon it will be evidently that of the working load. But as the load starts from a state of rest, the velocity is an accelerated one from the moment of starting till that in which the maximum speed of ascent is attained, and during this

time the strain upon the rope will be greater than that due to the load since a portion of the force exerted is expended in giving velocity to the load. The strain upon the rope during the time of accelerated motion is given by the following formula: $L = W \times \frac{W s}{32 \cdot 2 t}$ in which L is the load required, W the weight of the working load, s the full speed in feet a second, and t the time in seconds during which the accelerated motion takes place. Thus if the working load be 2 tons and the full velocity 10 feet a second, the strains upon the rope will be $2 + \frac{2 \times 10}{32 \cdot 2 \times 5} = 2 + \frac{20}{161}$ tons, assuming that five seconds are occupied in getting up the speed.

One disadvantage of wire ropes is, that in passing over the pulley and in coiling round the drum they raise the load by a series of short vertical jumps, and thereby occasion a jerky strain, which tends to cause a rupture of the wires. This jerky motion, which is greatest in flat ropes, is diminished by increasing the diameter of the drum. Another serious disadvantage to be guarded against in using wire ropes is their liability to break suddenly without having previously exhibited any indications of weakness.

Horse Whims.—The apparatus by which horse-power is applied to the raising of mineral in the shaft is shown in Figs. 461 and 462. In the Cornish "whim," as this structure is called, the horses are yoked to the ends of two radial arms, formed by a large horizontal beam of timber passing through a mortice in the upright axle. These arms are strengthened by two longitudinal straps or fishes applied through about two-thirds of their length. The rope barrel is a plain cylindrical cage formed by nailing straight boards to the outsides of three horizontal wooden rings, placed at different heights, and supported by arms morticed through the axle. The lower ring is carried by the top of the long beam, and another intersecting it at right angles, and the two upper ones by similar cross arms set at an angle of $22\frac{1}{2}$ degrees to each other. The whole cage is further supported by diagonal struts below the lower ring and resting against the sides of the axle near its lower end. The shaft is square at the intersection of the long cross bar, and is chamfered down to an octagonal section, above and below, with cylindrical ends, the cylindrical parts being tired with wrought-iron rings for securing the hold of the pivots. The framing is formed of two short inclined standards, united by a long transverse bar, to the centre of which is affixed the bearing of the top spindle. The guide pulleys over the top of the shaft are of small diameter, the framing giving a clear head room of about 8 feet only; the axis of one is placed a little higher than that of the other, in order that the rope may lead to its proper place on the drum. The diameter of the path described by the horses is 36 feet, that of the drum being 12 feet; the depth or height of the drum, or the receiving surface for the ropes, is 56 inches. The kibbles for horse whims are estimated to carry $2\frac{1}{2}$ cwts. Round hempen ropes, of 6 or 7 inches (circumference), or chains of $\frac{7}{16}$ths to $\frac{1}{2}$ inch iron are employed. For depths of less than 40 fathoms, one horse is sufficient, but two are employed for drawing from any greater depth. The speed at which the load moves in the shaft is from 75 to 100 feet per minute, the horses during the same time passing over about three times that space, or at the rate of about $3\frac{1}{2}$ to 4 miles per hour.

The vertical shaft in the German horse-whim, Figs. 463 and 464, is of considerable length; the rope drums are placed near the top, and are carried on a platform formed by four arms overlapping the shaft, supported at the ends by struts, which are nailed to the axle at about one-third of its height above the bottom bearing. The lower drum is fastened to the shaft, the upper one is loose,

and can be connected with the lower one by a wooden coupling pin. The brake works on a projecting part of the upper drum, and serves either to stop the whim when both drums are connected, or the top one only when the pin is taken out, which is done when altering the amount of rope out in changing the draught from a higher to a lower level, or the reverse. The upper drum in this case runs on friction rollers on the upper surface of the lower one. The bearing of the foot spindle rests upon a pair of adjusting wedges on a short pillar of masonry; to the top bearing is attached a horizontal beam, carried by two diagonal struts called spiessbaum, which also support a conical roof covering the rope drums and a gallery projecting from the house above the shaft. The horses are attached to a turning bar attached to the lower end of a projecting diagonal arm (schwengel) fixed at the upper end to the shaft and lower drum, and also supported at about half its length by a horizontal strut, which are hung by staples to the lower end of the shaft. Two poles with spiked ends (schlepspiese) are used to prevent the horses being dragged back by the weight of the loaded tub when the whim is stopped. The tubs are of a prismatic form, resting on rollers between wooden guides on the shaft, and are drawn by round wire ropes. The capacity of the tubs is about 2000 cubic inches; the radius of the path of the horses, 19 feet; the core of the drums, 6 feet; depth of the coil, 13 inches; the vertical shaft is 23 feet long and 17 inches square.

The Cornish water-whim is shown in Figs. 465 and 466. It is driven by an overshot water wheel, carrying a spur wheel of thirty-six teeth, which gears into a pinion with sixteen teeth on an intermediate shaft, whose journals are made to slide laterally in their bearings. Two bevel wheels are fixed on to this shaft at a distance from each other somewhat greater than the diameter of the horizontal mitre wheel on the upright shaft of the whim. By means of the reversing lever, the horizontal shaft can be moved sideways, so as to cause one or other of the two lower mitre wheels to drive that on the drum shaft, the left-hand one producing forward, and the right-hand one backward motion. The drums are intended for flat ropes, which are guided by a frame or cage with six wooden arms, set in cast-iron seating rings resembling those of the water wheel. The vertical shaft carries a second mitre wheel, which gears into a smaller one on a shaft carrying a small fly-wheel, serving as a brake drum. A strap on the brake shaft drives a pulley on a small shaft close to the ground, which lifts a weight passing over a roller at the top of a signal board. The path of the weight is proportional to that of the kibble in the shaft, so that the position of the latter is constantly shown by the place of the weight on the board. The buckets of the water wheel are made of a single board, an imperfect construction giving cells of small capacity, and now rarely employed. The load drawn at each ascent of the kibble is about $3\frac{1}{2}$ cwt.

A water whim with underground wheel, used in the Harz mines, is shown in Figs. 467 and 468. The drawings represent the ordinary arrangement adopted for a direct-acting water whim in the German mines. The rope drums are on the same shaft with the overshot water wheel, which is provided with two systems of buckets opening in opposite directions, each of which is provided with a separate sluice, not shown in the drawings; the buckets are formed of wood, in two pieces, set in wooden shroudings and backings. The framing of the arms is that usually adopted in Germany for large wooden wheels, known as "Dutch framing;" the ring is carried up either side by four principal arms laid in pairs at right angles to each other, and overlapping the sides of the square shaft, and eight intermediate diagonal arms or struts (hilfs armen) which are arranged in pairs forming V's, the apices of the V's resting on the centres of the sides of the shaft. One of the rope drums, that nearest to the water wheel, is fixed to the shaft; it is made entirely of wood, the framing of the

arms being similar to that of the wheel. The outer rope drum is loose on the shaft; it is carried by six cast-iron arms on either side, which turn on a pair of cast-iron rings keyed on to the shaft. Each of these rings has four square holes sunk into it to receive the points of the locking hooks, which turn on a shaft attached to the inside of the cage formed by the two sets of arms. These hooks are turned by a handle projecting from the outside of the drum, the coil of which fits into a catch. There are two brakes; one stops the loose drum when adjusting the amount of rope to be paid out; the other, which is used for stopping the wheel, works on a wooden disc placed between the rope drums and the water wheel. The journals of the main shaft project from a cross formed by two plates of cast iron intersecting at right angles, and surrounded by a ring; the arms of the cross are sunk into mortices in the wood, the ring forming an outside tire. This kind of journal is called a "kreuzzapfen."

Figs. 469 and 470 show the arrangement commonly adopted in Cornwall in winding from shallow shafts by steam power. The engine-house is placed near the centre of the ground, the outer end of the beam, the connecting rod, and the crank, being the only exposed parts of machinery. The drums on which the drawing chains are received are fixed horizontally on a vertical shaft, which receives motion from the engine by a horizontal bevel wheel at the lower end gearing into a similar wheel of equal diameter placed vertically and at the end of the fly-wheel shaft. The load is drawn by single link iron chains. The receiving surface of the drums is packed with wood, forming a cylinder of 4 feet in diameter.

The chains are in single lengths, one for each shaft; the ends are carried over guide rollers and hang down the shafts, having the kibbles attached to them by hooks and yokes. Each chain is carried twice round its own section of the drum, but is not made fast to it. The diameter of the path of the crank, probably equal to the length of stroke in the cylinder, is 5 feet. The wooden drum is surrounded by a skeleton cast-iron frame or cage with projecting horns, for keeping the chains in their proper places. The actual distances of the two shafts from the engine are 35 fathoms and 24 fathoms respectively.

The ores are brought up in wrought-iron buckets or kibbles, which are drawn through the shafts without the use of guide rods. The mouth of each shaft is closed by two trap doors with narrow channels in the middle for the passage of the chains; they rest against inclined seats, and are lifted by the ascending kibble when it comes to the surface. The average diameter of the round iron bars, of which drawing chains employed in Cornwall at the present time are made, is about $\frac{9}{16}$ of an inch for deep mines with steam whims; or tapered chains are sometimes used, in which part is of $\frac{1}{2}$ inch and part of $\frac{11}{16}$ of an inch diameter; the larger size, of $\frac{3}{4}$ of an inch, is but rarely used. The average weight of the kibble when empty is from 6 cwt. to 10 cwt.; the load is from 5 cwt. to 7 cwt. The working speed in shafts of varying inclination sunk on the vein is from 150 feet to 170 feet per minute; a much higher speed may be allowed in shafts where skips or boxes travelling on wooden rods are employed.

Models of all the foregoing whims may be seen in Jermyn Street Museum, London.

Hauling Engines.—When considering the advantages of an application of steam power to the work of haulage, the first question that presents itself is, What proportion of the force developed may be utilized? In other words, what is the maximum useful effect obtainable from a hauling engine working under the generally unfavourable conditions prevailing upon underground railways? It is obviously impossible to determine this question in a general manner, since it involves conditions that vary very widely in character; and even by assuming conditions in order to assign a particular

value to the useful effect, the question can only be determined by direct experiments. Such experiments have, however, been made for some cases; and from those undertaken with great care by Nicholas Wood, we learn that, where no special source of loss exists, underground hauling engines are capable of realizing an efficient performance varying from 40 to 50 per cent. of the pressure of the steam upon the piston. With the improved engines of the present day this value may be safely increased 10 per cent., so that we may assume the efficiency of a hauling engine to be from 50 to 60 per cent. estimated in coal conveyed. This value, which compares very favourably with that of horse-power, may be taken as a basis upon which to found any calculations relating to the performance of hauling engines.

The direct employment of steam in the operations of haulage is, however, not without disadvantages. If the boilers are placed underground, their position is by no means arbitrary; for it is necessary so to place them that the products of combustion may pass as directly as possible to the up-cast without traversing drifts used as a travelling road, and that there may be no danger of an explosion from firedamp reaching the furnaces. These are disadvantages attending the direct employment of steam of a somewhat grave character, which cannot be entirely got rid of when the boilers are placed underground, and in order to avoid the danger as far as is possible, it may become necessary to adopt a position but ill suited to the requirements of the engines. It is easy to conceive how this condition may operate to determine in some degree the position of the engines, which ought to be chosen solely to satisfy the requirements of the traction. One means, not unfrequently adopted, of obviating these difficulties, consists in erecting the boilers at surface, and in conducting the steam down the shaft, and to the points where the engines are fixed, through iron pipes. But this expedient introduces difficulties of another kind. To prevent the condensation of the steam by the radiation of heat from the pipes, the latter have to be well coated with a suitable non-conducting material. But whatever expense may be incurred in providing this protective covering, the remedy is but partially effectual; in all cases a large amount of condensation inevitably takes place, and the evil thus caused will obviously become more serious as the distance of the engines from the boilers increases. But besides these drawbacks, there is in every case the disadvantage arising from the heating of the atmosphere underground by the exhaust steam. It is true that this objection to the direct use of steam may be to some extent removed by the adoption of suitable arrangements; but such arrangements have to be adopted, and the evil even then admits of only partial remedy.

It is easy to see that if a complete system of mechanical haulage is to be established in the place of the horses now largely employed, it must be possible to fix an engine in the most favourable position for the traction, and in any part of the workings, for such a system would involve the use of small engines, capable of being readily moved from place to place, to serve the less important points, as the workings advance. The requirements of the haulage are partially fulfilled by the system of erecting both boilers and engines at surface, and in transmitting the force down the shaft by means of an endless rope.

This system, however, though it gives good results in some cases, leads to complication, and is limited in its application. Perfect efficiency and completeness can only be obtained by the use of several independent engines, situate at various points in the workings, and designed and proportioned in their dimensions to the work they have to perform and the conditions under which they are to operate. It is obviously apparent that in such a system of haulage the direct application

of steam is altogether impracticable, and it becomes therefore desirable to find a means through which its force may be conveniently transmitted.

The only satisfactory solution of this problem appears to lie in the adoption of compressed air. It has already been shown that when air-compressing machinery is erected at surface the compressed fluid can be conducted without difficulty, and with only a trifling degree of waste, down the shaft, and thence to the most remote part of the workings. The discharge of this air into the atmosphere of the mine, so far from occasioning inconvenience, as in the case of steam, tends to reduce the temperature and to promote the ventilation. In this respect also it possesses an advantage over water, the presence of which, after its discharge from the engines, is more or less seriously objectionable.

Compressed air may be easily and cheaply conveyed to any part of the workings through branch pipes of small diameter, laid from the primary and secondary mains in the principal roads; hence, not only may the hauling engines be placed in positions most favourable to the traction, but rock-boring and coal-cutting machines may be supplied from the same system of pipes as the hauling engines. This is a matter of no small importance, since the general adoption of machine drills and coal cutters is inevitable. With a well-laid-out system of air-pipes and small and compact hauling engines suitably placed, the operations of haulage might be performed with a rapidity suited to the requirements of the present large outputs, and at a cost far below that now incurred even by the improved means in use in many places. Probably in no department of mining engineering is there such an opportunity for the exercise of inventive skill, and for the application of recent discoveries in mechanical science, as in this of haulage by means of compressed air; and it may be confidently believed that, as the cost of manual labour continues to increase, the necessity for the use of such means will become greater. The only objection to the employment of compressed air lies in the loss of the motive force which it occasions; but this loss is far more than compensated by the advantages afforded in other directions.

An underground hauling engine which satisfies very completely all the requirements of such a machine is shown in Figs. 471 and 472. It is known as Stevens' engine, and is manufactured by the Uskside Company, Newport. A glance at the drawings will show that the designer has kept in view the conditions under which hauling engines have to work. It is claimed for this engine: 1. That it is very compact and portable. The No. 1 size, which with 20 lbs. pressure will indicate 6 horse-power, and having two drums of 2 feet diameter, has for its extreme dimensions $6 \cdot 9 \times 4 \cdot 0 \times 3 \cdot 4$ feet, its weight being only 29 cwt. 2. That no foundation is required. The engine, as shown by the drawing, is fixed by spiking or screwing down to timbers, and, when necessary, by wedging to the roof; and 3. That its general arrangement is extremely simple. The drums, which work on the second motion, are loose on the shaft, and have independent brakes and clutch for throwing them in and out of gear. All the handles are brought together at the back of the engine, so that it may be easily managed by a lad. If thought desirable, the engine may be provided with tram or with road wheels.

Instead of being fitted with loose drums, the engine may be arranged with one or more wheels for working endless chains, or with clip drums, if an endless rope is preferred.

The common sizes are: the No. 1, with 7-inch cylinder and 2-foot drums, the extreme dimensions being $6 \cdot 9 \times 4 \cdot 0 \times 3 \cdot 4$ feet. The No. 2, with 9-inch cylinders and 2 foot 6 inch drums, the extreme dimensions of which are $7 \cdot 8 \times 4 \cdot 1 \times 3 \cdot 1$ feet. The A size, with two cylinders 10 inches in

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diameter by 14 inches stroke and 3 foot 6 inch drums. And the B size, with two cylinders 12 inches in diameter by 16 inches stroke and 4 foot 6 inch drums.

It may be remarked that this engine may often be advantageously used for winding during the operations of sinking.

An underground hauling engine, constructed by Mather and Platt, of Salford, is shown in Figs. 473 and 474. In order to secure steady driving at all speeds, the power is obtained from two cylinders of equal diameter, cast together with their respective valve boxes in one piece, having one inlet and outlet for steam and exhaust common to both. The pistons may be put in and taken out from the back of the engine, without displacing any of the working parts; hence the ordinary cylinder covers at the stuffing-box ends are dispensed with. The stuffing boxes of the piston rods are simply cast on the ends of the cylinders. The pistons are of Mather and Platt's well-known construction, with their patent elastic metallic packing. A single slide-bar is used, with a cast-iron cross-head clipping and sliding upon it, having a plate on the under side to tighten up. The breadth and length of wearing surface in the cross-head, together with the mode of lubrication employed, will render the wear inappreciable. The connecting rods of wrought iron communicate the power at quarter centres to a double-sweep wrought-iron crank-shaft, which has its bearings in the engine-bed at each side. Beyond the necks of the crank-shaft are placed two light fly-wheels about 4 feet diameter. The slide valves are fitted with a reversing motion worked from two excentrics in the ordinary way, but fitted in a very substantial and simple manner. The engine-bed is cast in one piece, and possesses great rigidity and strength, with small expenditure of material. The hauling gear is driven by a pinion on the fly-wheel shaft between the cranks, the second motion shaft being carried by continuation of the-engine bed, which ties the crank and second motion-shaft securely together. The hauling wheels are fitted with special friction clutch-boxes, to prevent breakage in case of the fouling of a waggon in the "roads." The whole engine with hauling gear is self-contained, without any bearings beyond the engine-bed, for working two chains, while four or more chains may be worked by simply extending the second motion-shaft right and left.

The engine shown in the drawings is one of several made for the Blackwell Colliery Company, with two cylinders each 10 inches diameter, 16 inches stroke, working with steam or compressed air of 30 lbs. pressure, to haul up gradients of 1 in 16, 800 tons of coal per day of eight hours the distance of about one mile.

The Winding Drum.—The drawing rope, after passing over the pulley at the top of the head-stocks, is led to the winding drum, upon which it is coiled. This drum may be either cylindrical or conical in form, and it may be made to revolve either upon a horizontal or upon a vertical axis. The latter arrangement is now, however, rarely adopted, and we shall therefore consider only the case of horizontal drums. A drum consists of a barrel, upon which the rope is wound, and two side-pieces or cheeks, called flanges, the use of which is to prevent the rope from slipping off the barrel. These two portions are carried upon arms connected to a central boss, through which the shaft passes. The material used in the construction of winding drums is most frequently iron, a combination of both cast and wrought iron being usually adopted. The barrel is cast in segments, and put together by being bolted through flanges provided for that purpose. The arms are also of cast iron, and are bolted to the side flanges of the barrel, a portion of the rim being cast upon each arm, in some cases. The inner ends of the arms are fitted into a cast-iron boss, and secured in position by turned bolts in bored holes. The shaft is of wrought iron, and should be forged from the best

scrap; to secure the bosses, which should be bored out to the exact diameter of the shaft, the latter is turned and provided with key-beds cut into it. A similar mode of construction is adopted when the drum is conical in form, in so far as its essential component parts are concerned. With this form, the drum presents the appearance of a double cone, or two cones, or frustra of cones placed base to base, and the rope is fixed so as to be ascending upon one cone while it is descending upon the other.

The principal object of this arrangement of the drum and the rope is to ensure the regular coiling of the latter; but the arrangement contributes, in a manner to be pointed out hereafter, to equalize the resistance to be overcome by the engine.

The diameter of a winding drum is determined mainly by the nature of the rope to be used, a much larger diameter being required for wire ropes than hempen ropes; but it should also bear some proportion to the diameter of the rope of a given material, since it is obvious that the thicker the less readily it will coil upon a cylinder of a given diameter. A suitable diameter of the drum may be obtained in the following manner: Assuming 10 feet to be the minimum diameter for a wire rope 1 inch in circumference, add 6 inches to the diameter of the drum for every increase of a quarter of an inch in the circumference of the rope. Thus a rope $2\frac{1}{2}$ inches in circumference will require a drum $10 + 4\cdot5 = 14$ feet 6 inches in diameter, and a rope of $3\frac{1}{2}$ inches will require a drum of $10 + 7\cdot5 = 17$ feet 6 inches. It has already been pointed out that as the diameter of the pulley and of the drum is increased the life of the rope is lengthened, and it is obvious that, determined by the conditions of wear in the rope, the diameters of the pulley and of the drum should be equal.

Round rope is wound upon the drum in parallel coils, and in some instances it is made to rise and return upon itself on cylindrical drums for the purpose of diminishing the length of the latter; the arrangement is, however, unfavourable to the durability of the rope. When the drums are conical the overlap is, of course, impossible, and the same necessity for it does not exist. A flat rope is always wound upon itself, so that its coils are all in the same vertical plane; hence, practically, the diameter of the drum is constantly increasing or decreasing, and the velocity of the load consequently accelerated or retarded. This variation tends, of itself, to render the work of the engine unequal during the raising of the load. But it will be observed that this tendency is counteracted by a variation in the value of the load during the same time, and that, consequently, this overlap of the rope results in an equalization of the work of the engine. When the load starts from the bottom of the shaft it has its maximum value, for at that moment the weight of the whole length of rope is added to that of the cage with its contained load; and it has been shown that the resistance due to the inertia of the mass must also be overcome at the moment of starting. But when the load has thus its maximum value, the diameter of the drum is at its minimum value, since the rope is then wholly uncoiled, and hence the leverage in favour of the load will also have reached its lowest limit. Moreover, as the other portion of the rope will, at the same moment, be wholly coiled upon the drum, the latter will, relatively to this portion, have attained its greatest diameter, and consequently the leverage in favour of the descending load, consisting of the empty cage, its highest value. These circumstances are evidently favourable to the equalization of the work of the engine, and it will be seen that these circumstances continue throughout the time of winding. For, as the one portion of the rope ascends and diminishes in weight, the leverage in favour of it increases in a like degree; and as the other portion descends and increases in weight the leverage in favour of it is diminished in like manner. The same advantages are obtained with round ropes,

though under less favourable conditions, by making the drum conical. When the drum has this form, there is a liability of the rope slipping, if any hitch should occur to slacken it, and such a slipping would probably cause rupture of the rope. The length, or as it is sometimes described, the breadth of the drum is obviously least with the rope.

When both portions of a round rope are wound upon the same drum, the length of the latter will be that required by a single rope, since one portion is being unwound while the other is being coiled upon the drum, so that the sum of the lengths coiled at any given moment is equal to the length of one portion of the rope. In such a case one portion of the rope is wound over the drum, and the other portion under the drum. As both portions are wound over the pulley, one is thus wound in contrary directions, a circumstance unfavourable to its durability. The evil is removed by the use of two drums revolving in contrary directions, an arrangement which allows both portions of the rope to be passed over the drum. The details of fixing the rope to the drum are very simple. Usually a notch or a groove is provided on the drum to receive the end of the rope which is held in by wedging. To avoid bringing the strain of the load upon the fastened end of the rope, the length is always regulated to leave two or three coils upon the drum when the cage is at the bottom of the shaft.

The position of the drums is a matter of importance. Relatively to the engine, they may be placed with their axes in the horizontal plane passing through the piston rod, or they may be placed above the cylinders with their axes in the vertical plane passing through the piston rod. Each of these positions possesses some advantages to be noticed hereafter; the former appears, however, to be preferable, and it is more commonly adopted. Relatively to the pulleys, the level of the drums should, where easily practicable, be so adjusted that the inclined portion of the rope shall not make a very acute angle with the vertical portion; hence the higher the pulleys the greater should be the interval between the drums and the pit mouth. Too great a distance is, however, objectionable, by reason of the sagging and swaying of the rope. The best arrangement, where it can be adopted without difficulty, consists in erecting the drums at a higher level than the pit mouth. This is one of the advantages obtained by placing the drums over the steam cylinders. An essential condition to be observed is to place the drum and its corresponding pulley in the same vertical plane, and strictly perpendicular to their axes of rotation. A slight irregularity in this respect, by forcing the rope to deviate from one side to the other, gives rise to considerable lateral friction, which tends to rapidly destroy the rope.

The question of regulating the load to be lifted is one of the most important relating to the operations of winding. The variation in the value of the load is due, as we have seen, to the constantly diminishing length of the ascending rope, and the constantly increasing length of the descending rope. As the weight of the rope is great relatively to that of the useful load, it is obvious that this variation must be great also. To take an example, suppose a depth of shaft equal to 340 yards, a useful load of 16 cwt. of coal and wire rope weighing 10 lbs. a fathom, or 5 lbs. a yard. As the cages are equal in weight, they may be left out of the question. At starting the load to be lifted is $16 \times 112 = 1792$ lbs. of coals $+ 340 \times 5 = 1700$ lbs. of rope, $= 3492$ lbs. We are not now considering the strain upon the engine, which question would involve the taking into account of the inertia of the mass, but only directing attention to the alteration which takes place in the value of the load during the time of ascent. Now it will be observed that as the length of the ascending rope is constantly diminishing, its weight is constantly

decreasing from 1700 lbs. at starting to zero at the landing place at the mouth of the shaft. And as the length of the descending rope is constantly increasing, its weight is being constantly augmented, from zero at starting to 1700 lbs. at the moment of stopping at the bottom of the shaft. Moreover, as this weight acts as a counterbalance to the ascending load, the latter, on arriving at surface, will be reduced to $3492 - (1700 \times 2) = 92$ lbs. Thus during the time of ascent the value of the load has been diminishing from 3492 lbs. to 92 lbs. It is easy to see that this value may become negative. Suppose the depth of the shaft to be 360 yards instead of 340 yards. In such a case the weight of the load on arriving at surface will be $3592 - 3600 = -8$ lbs.; that is, the descending load will have overrun the ascending load, and the engine will have to oppose a retarding force of 8 lbs.

This great variation in the load to be raised is manifestly very unfavourable to the work of a steam engine, and hence it becomes necessary to provide means for regulating the load. It has been suggested that this end might be attained by employing a variable degree of expansion. But a moment's consideration will show such means to be utterly inefficient. If it were a question merely of equalizing the speed of the engine, a skilfully contrived and carefully managed expansion would doubtless effect the purpose required. But what is needed is an equalizing of the work developed at each revolution. A high degree of expansion is demanded by the exigencies of economy in the consumption of fuel. But a high degree of expansion pre-supposes not only a nearly uniform speed, but also dynamical equilibrium among the various forces exerted upon the engine. Hence it is evident that the requirements will not be satisfied by the adoption of a variable expansion. Other means of regulating the load had therefore to be sought, and they have been found in the counterweight and the conical drum. It has been already pointed out that the regulating effect of the conical drum is more or less fully obtained, when a flat rope is used, by coiling the rope upon itself, whereby the virtual diameter of the drum is made to vary. We shall, therefore, consider the counterbalancing of the load and the coning of the drum relatively to the case of round rope. These means solve the problem in a satisfactory manner; and it may be remarked that the former is more common in England, where it was first employed, and the latter on the Continent, where it has received the most attention.

The counterweight usually consists of a number of excessively heavy iron links, suspended in a pit or well from 30 to 50 yards deep, provided for that purpose. To these links is attached a rope, which is fixed to the drum-shaft. The length of the balance-chain is equal to the depth of the pit in which it hangs, and it is connected to the drum-shaft in such a manner relatively to its length, that when the drawing ropes are at the starting point, that is, when one cage is at surface and the other at the bottom of the shaft, its whole length is hanging in the pit. The rope by which it is wound up is also arranged so that the whole of the balance-chain may rest upon the bottom of the pit when the ascending and the descending cages arrive at the same point in the shaft. This rope is made to pass over the drum-shaft in a direction contrary to that of the drawing rope which it is intended to counterbalance. The action of the counterbalance will now be readily understood. At the moment of starting the engine, the whole of the links are suspended, and these, by their great weight, hold the drawing rope in equilibrium. As the latter ascends and is diminished in weight, both by reason of the reduction going on in its own length, and of the increase taking place at the same time in that of the descending rope, the links are being deposited at the bottom of the pit, and, as previously pointed out, the whole of the links will be resting upon the bottom when the cages meet in the shaft, at which moment the ascending and the descending ropes balance each other.

From the time when the cages pass each other, the weight of the descending rope preponderates, and this preponderance goes on increasing until the bottom of the shaft is reached. But from the moment when the descending cage passed the ascending one, the counterbalance chain is again being wound up, this time in the contrary direction; and as it is raised link by link, its weight counteracts the preponderating weight of the descending rope. Thus it will be seen that this system of counterbalancing, if it does not give perfect uniformity, yet solves the problem of regulating the load with sufficient completeness for practical purposes. The weight of the balance links must, of course, be proportioned to that of the rope, account being taken in the calculation of the diameter of the pulley or drum upon which it is wound. This diameter, it will be observed, is related to the depth of the pit or well in which the chain hangs. The pit is generally situate on the side of the drum farthest from the shaft. Sometimes, instead of the chain, a heavily loaded tub, or truck, is used as a counterweight. In this case, the tub is made to run upon rails suitably inclined. The inclination of the road is made to vary so as to be sharp near the upper end and flat at the lower end, for the purpose of obtaining a constantly increasing or diminishing resistance. During the time of drawing a load, the tub runs twice over the road, first descending and then ascending. Thus the force of traction exerted by the tub upon the rope to which it is attached is greatest at the moment of starting, null at the end of its course when the cages are at the same point in the shaft, and greatest again when the cages have reached the landing place; whence it will be seen that the action of the tub is precisely that of the balance-chain in the pit. By carefully determining the curve required, the counterbalancing of the rope may be in this way very completely accomplished, and often more easily, and at a less cost than by means of the chain.

The other means of regulating the load by means of a conical drum solves the problem less completely than the counterweight, but it possesses the advantage of leading to less complication; for every additional piece of machinery needing constant inspection increases the risk of failure. The question to be determined relatively to the conical drum is, what, under the given conditions, shall be the value of its mean diameter? This question, however, practically resolves itself into another, namely, what, under these conditions, can be its initial or least diameter? Here we have to deal with considerations of a conflicting character. The initial diameter most favourable to the durability of the ropes is the largest possible, for reasons already given. But the initial diameter most favourable to an equalizing of the moments of resistance in a deep shaft is the smallest possible, the number of coils upon the drum increasing as the diameter diminishes. It is evident that when wire ropes are used, the wear of the ropes will require a large initial diameter, since that wear will be determined by the least, and not by the mean diameter. The initial diameter should be proportioned to the thickness of the rope, in the manner already described for cylindrical drums, and the mean determined according to the conditions of the case. Thus it will be seen that the limits of variation are very narrow, and hence it results that the regulating effect is more or less imperfect. In practice, a common size of conical drum is 16 feet at the smaller end, and 20 feet at the other.

Large conical drums are sometimes provided with a spiral channel for the reception of the rope, the object of this arrangement being to prevent the rope from slipping. The slipping of the rope is a danger to be feared with conical drums; but if due care be taken to wind the rope on very tightly at first, this danger is not great upon drums having the inclination usually adopted. Of course, checks or side rims are required, as in the case of cylindrical drums, to guide the rope from slipping off the drum altogether. This matter has been made the subject of legislative control, and it is enacted

that, there shall be on the drum of every machine used for lowering or raising persons, such flanges or horns, and also, when the drum is conical, such other appliances as may be sufficient to prevent the rope from slipping. It is hardly necessary to add that the component parts of a winding drum should possess ample dimensions and be strongly connected together, and that the foundations upon which the bearings of the shaft rest should be massive and securely placed, so as to render the drum capable of resisting not only the ordinary but accidental shocks, and of serving as a protective medium interposed between the force and the engine.

WINDING ENGINES.—In order to understand the requirements of a winding engine, it is necessary to consider carefully the work demanded of it. Such a consideration will at once show us that an engine used for winding purposes is required to work under conditions differing widely from those to which an engine employed in driving machinery is subjected. In lifting a loaded cage from its resting place at the bottom of the shaft, the engine must start slowly, at first in one direction for the purpose of lifting the cage at surface off the keeps, and then in the contrary direction to lower the empty cage in the shaft, and to raise the loaded one. But it is to be observed that, during the time that the empty cage is being lifted off the keeps, the loaded cage is resting at the bottom of the shaft, and that, consequently, the latter does not, during that operation, exert its counterbalancing effect upon the former. When the empty cage has descended below the keeps, the force is applied to the loaded cage at the bottom, which is then lifted, and which, during a time, moves with an accelerated velocity. During this time, as already shown, the resistance is greatest. After the full velocity has been attained, it remains uniform for a few seconds; it is then retarded, and when the cage has arrived within a certain distance of the surface, a signal warns the engine-man to cut off the steam. From this point, the ascent is made by the *vis viva* of the mass in motion. As soon as the cage has ascended above the shaft mouth, the engine-man reverses his engine, and thereby brings the whole instantly to a stand. The cage having been stopped above the level of the keeps, a slight movement, to allow the steam in the cylinder to escape, gently drops the load upon the keeps. And here it is to be again remarked that, during the time of raising the loaded cage above the keeps, and lowering it upon them, it is not counterbalanced by the other cage, which is then resting at the bottom of the shaft.

Now if these operations be carefully viewed, it will be clearly perceived that, to ensure their regular performance, two conditions will have to be satisfied: first, the engine must possess a considerable excess of power to give it complete control over the load; and, second, it must be so constructed and regulated that the engine-man may have it completely under his control. Moreover, as it is of the utmost importance that the engine be always capable of performing the work required of it, and that, consequently, no failure to raise the load at any moment should be liable to occur, another condition to be satisfied is that, the design and the construction of the engine should be such as to reduce the chances of derangement to a minimum. These three conditions have acted to determine the type of engine employed for winding purposes.

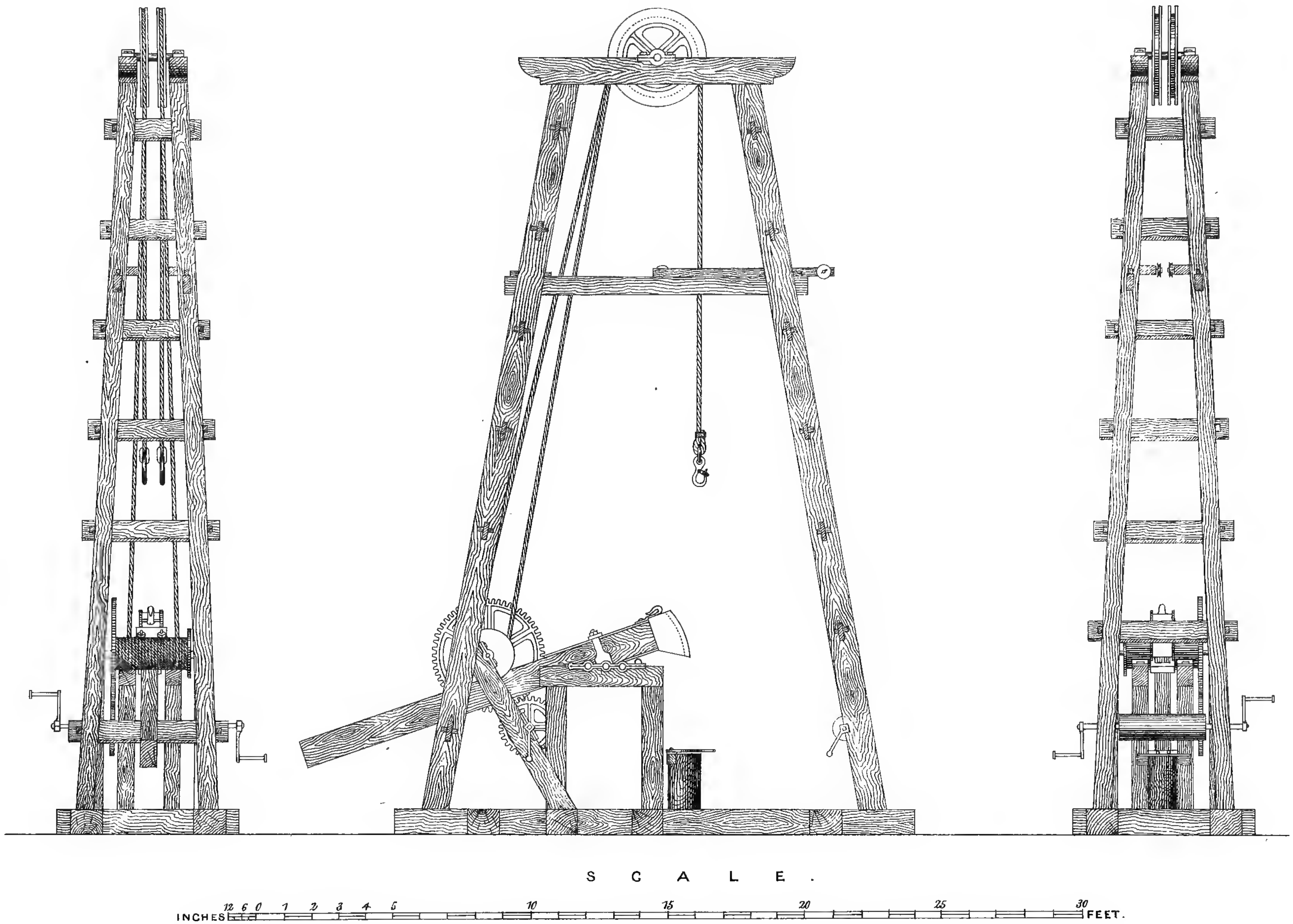
The most approved design of winding engine consists of two coupled cylinders, and is provided with a light fly-wheel. The use of this wheel is rather to furnish a means of controlling the motion by a brake than to regulate the motion, which is sufficiently effected by the mass of the winding drum, pulley, rope, and load. With an engine so constructed and controlled, the attendant has the force at his disposal sufficiently well in hand to enable him to perform promptly the operations we have described, without having to deal with the difficulties of the dead point.

To satisfy the third condition, to which attention has been directed, the number and the importance of the parts of the engine must be reduced to a minimum, especially those which are not constantly in sight, such as the valves, pistons, and stuffing boxes. To obtain the desired simplicity, it has been the custom to construct the engine to work at high pressure, without a greater degree of expansion than is to be given by the lead of the slide valve, and without, of course, condensation. These conditions, however, though favourable to simplicity, are unfavourable to economy of fuel, and as the cost of the latter has greatly increased of late, attention is being directed to the advantages of expansion. With the improved mechanical arrangements of the present day, suitable expansion gear may be applied without adding much to the complexity of the whole, and accordingly we find the more recent engines designed to work with a variable expansion. For the same purpose of gaining simplicity, the piston rods are usually connected directly to the fly-wheel shaft, upon which the winding drums are fixed, so as to avoid the intervention of gearing. One advantage of this arrangement is, that inasmuch as there is but one revolving shaft, one brake is sufficient. The reversing gear adopted is similar in character to that employed on locomotives.

The cylinders may be placed either horizontally or vertically, the latter position being common in the north of England. Each of these positions possesses certain advantages. One advantage claimed for the vertical cylinder is, that the wear of the parts in rubbing contact is less, and more equal in that than in the horizontal position. But the objection to the latter on this ground must be regarded rather as theoretical than practical. It is also urged against the horizontal cylinder that, in consequence of the mode of connection adopted between it and the bed-plate, the parts are strained by unequal expansion and contraction due to varying temperatures, and that it occupies more space than the vertical cylinder. This latter objection is, however, of very little value, and as an equivalent set off to the former, it may be urged that the horizontal position of the cylinder gives greater stability than the vertical, and is besides more convenient. In favour of the vertical position, it is also claimed that, with such an arrangement of the cylinders, the winding drums are placed at a higher level, and that, in consequence, the angle made by the oblique with the vertical portion of the rope is increased, whereby the wear of the latter is lessened. This advantage is indisputable, but it must be borne in mind that by increasing this angle, the resultant is thrown farther out of the vertical, the consequences of which have already been noted. The chief gain derived from the higher level appears to be that it places the engine-man nearer the shaft, and allows him to obtain a better view of the shaft's mouth. In calculating the power requisite in a winding engine to perform a given work, we must bear in mind, first, that a considerable excess of power is required to give the engine complete control over the load, and second, that the engine must possess sufficient power to enable it to lift the load under the most unfavourable circumstances. It has already been pointed out that the loaded cage at surface is being raised and lowered while the other cage is resting at the bottom of the shaft, so that the former is deprived of the counterbalancing effect of the latter. Thus it will be seen that the engine may be, and at every winding is, required to work with only one rope, and consequently, it must possess sufficient power to do this, and still to have that excess which is needed to give it full control over the load. But it may also be required to lift the load under the unfavourable conditions when one of the pistons is at the dead point and the other at half centre, conditions most unfavourable to the engine. And hence it will be necessary to give the piston such a diameter as will enable it to do this easily.

BORING APPARATUS —— Boring Frame.

Fig 2. Fig. 1. Fig. 3

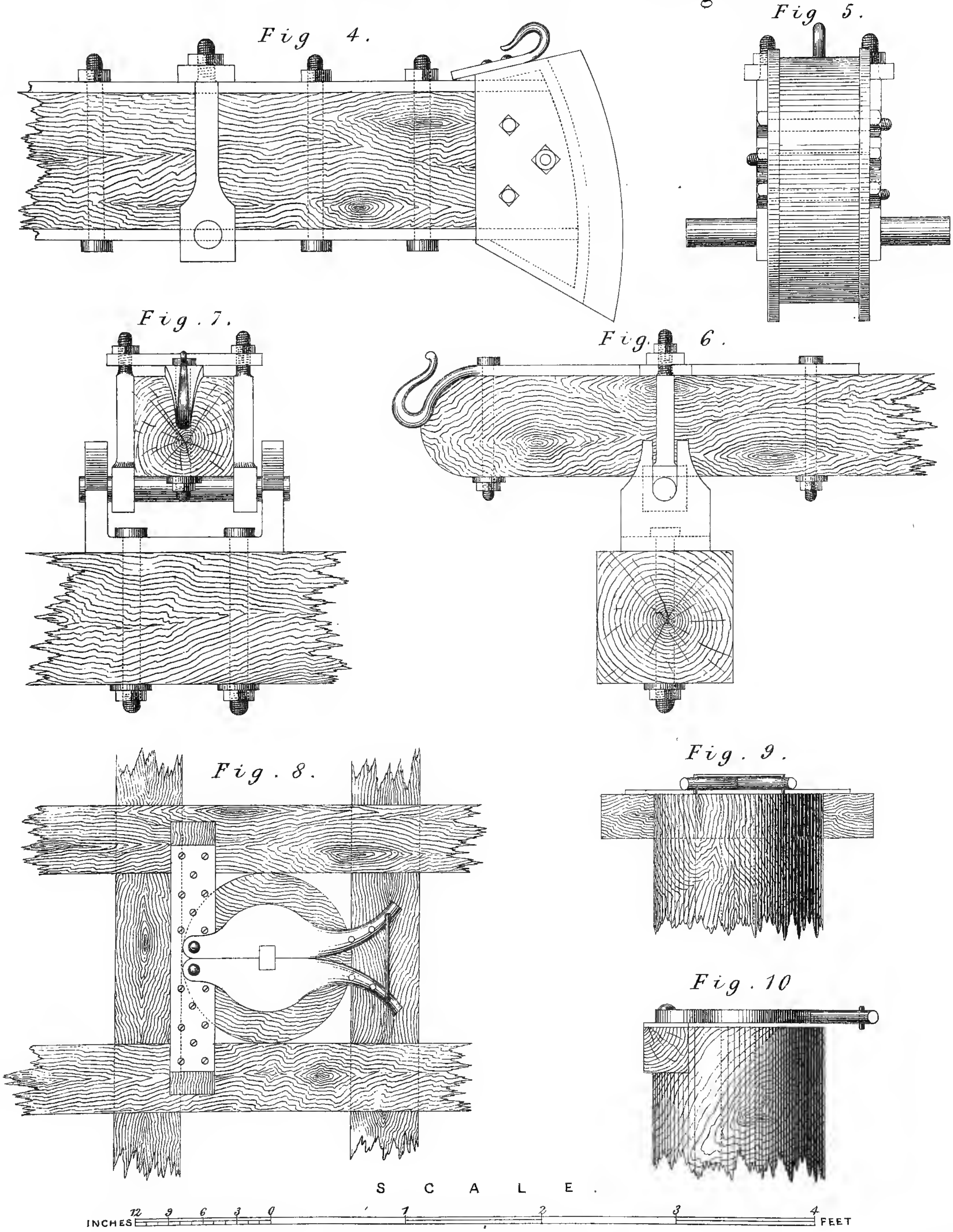


S C A L E.

G.G. ANDRÉ.

E & F.N. Spon. London & New York

BORING APPARATUS — Details of Boring Frame.



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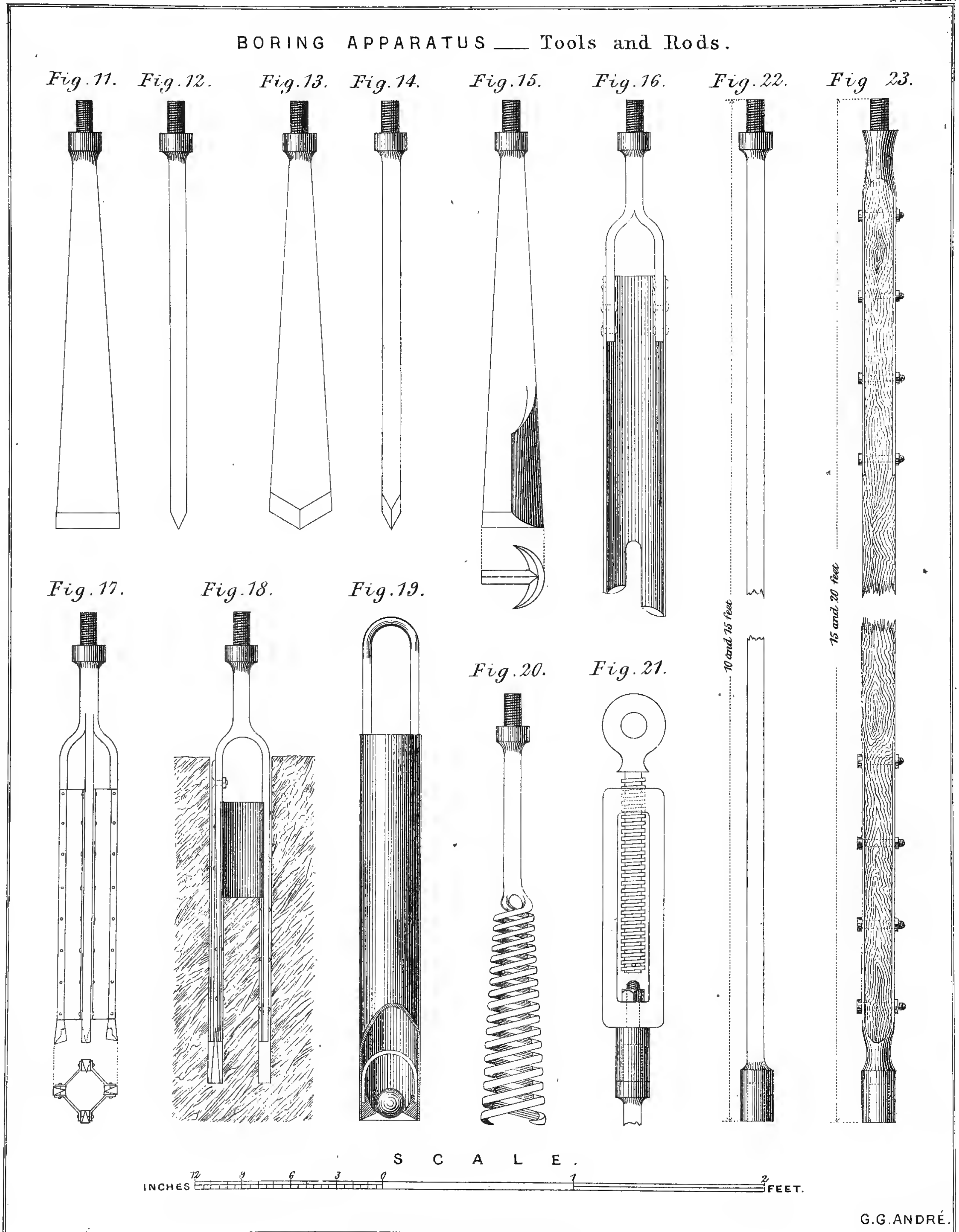
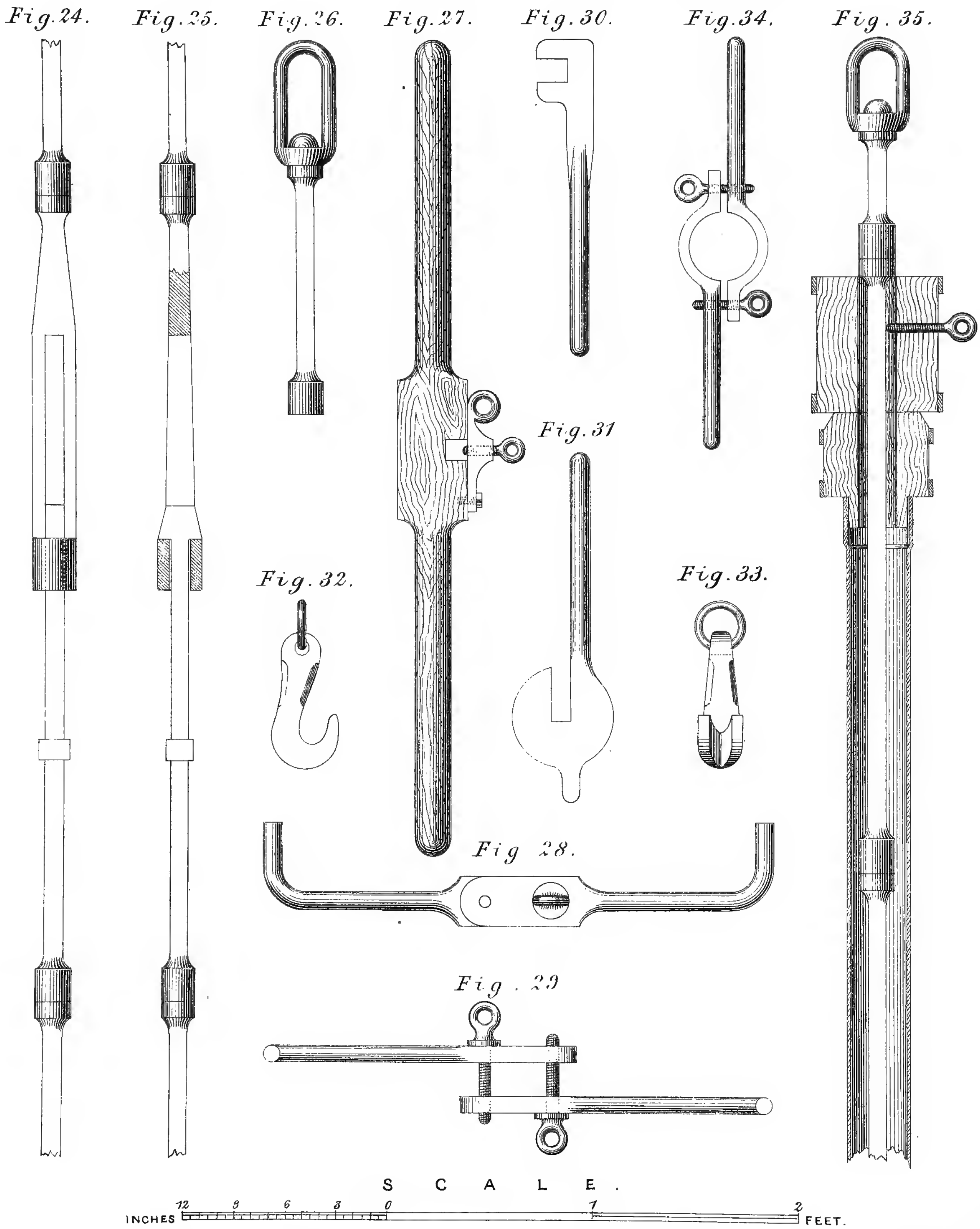


E & F. N. Spon, London & New York.

BORING APPARATUS — Rods and Tools.



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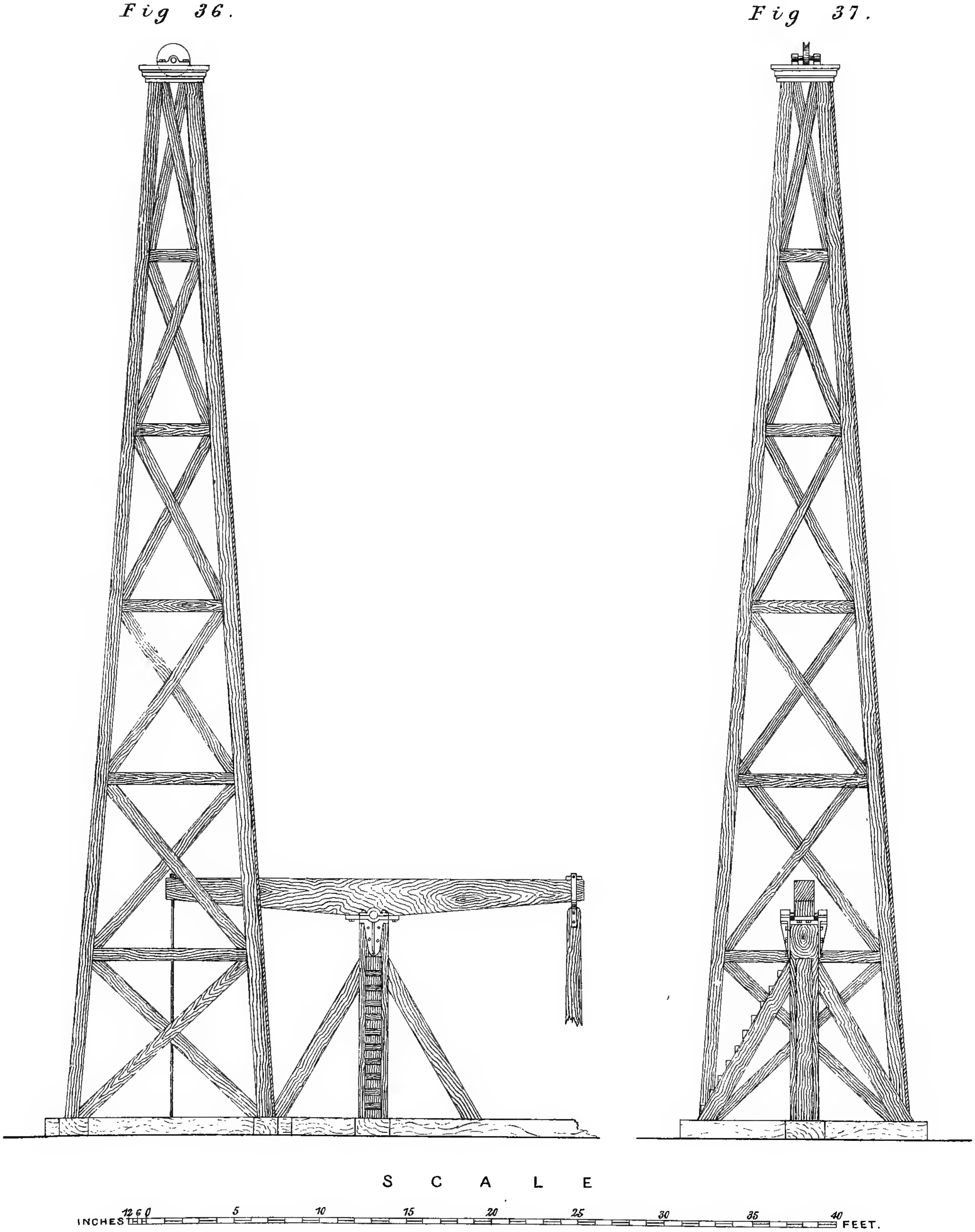
BORING APPARATUS — Boring Frame.



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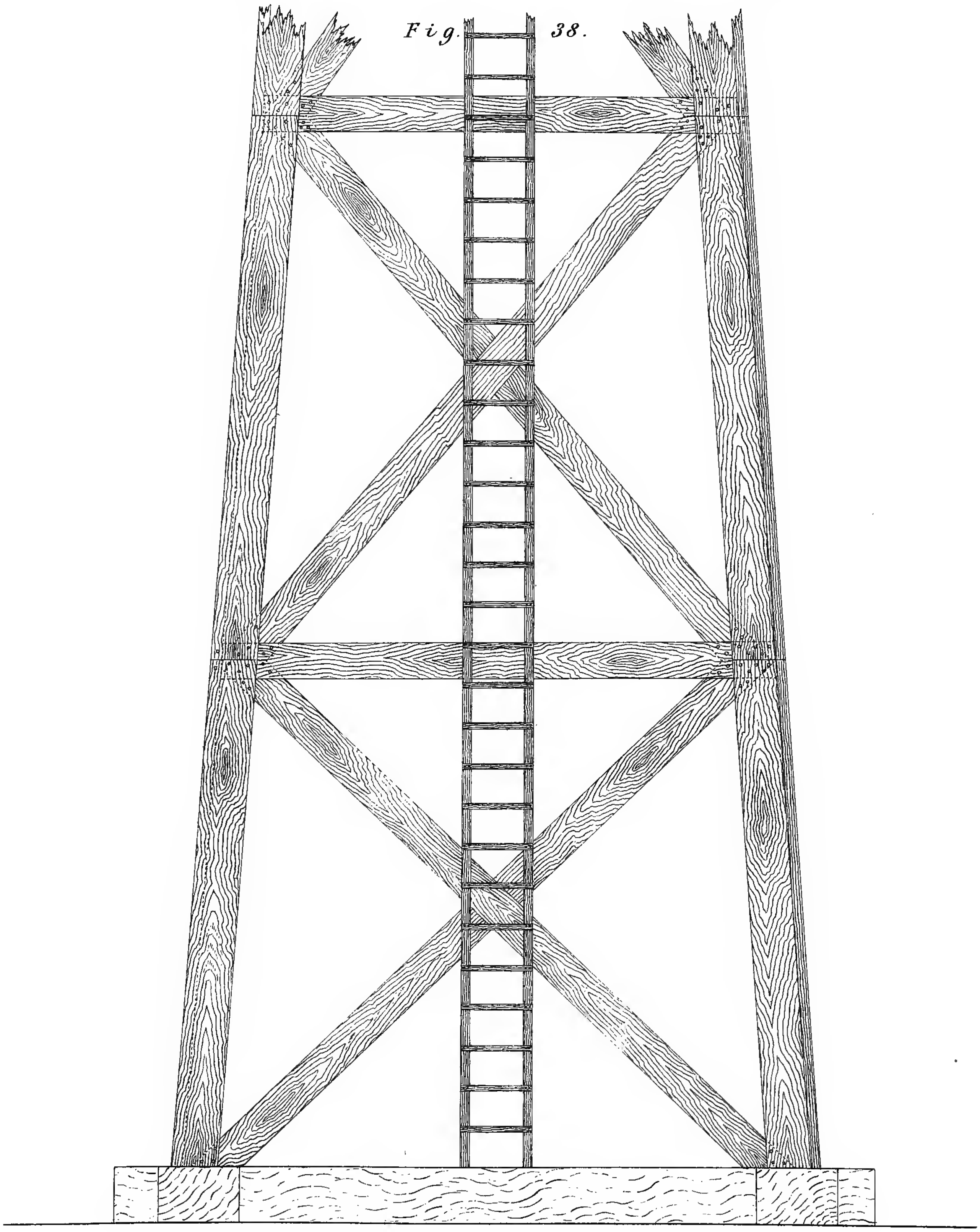
BORING APPARATUS —— Boring Frame.

Fig. 38.



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BORING APPARATUS — Details of Boring Frame.

Fig. 39.

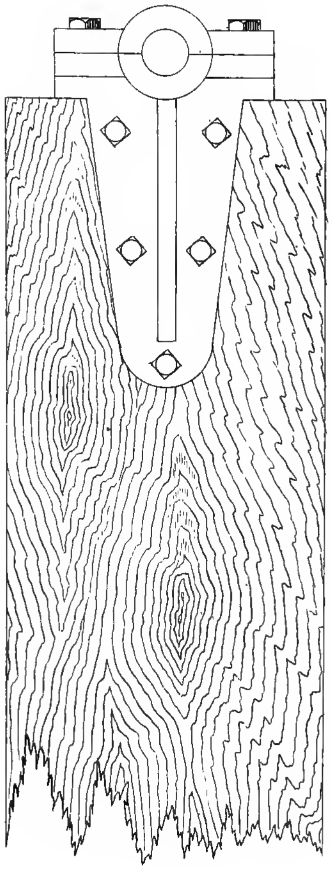


Fig 40.

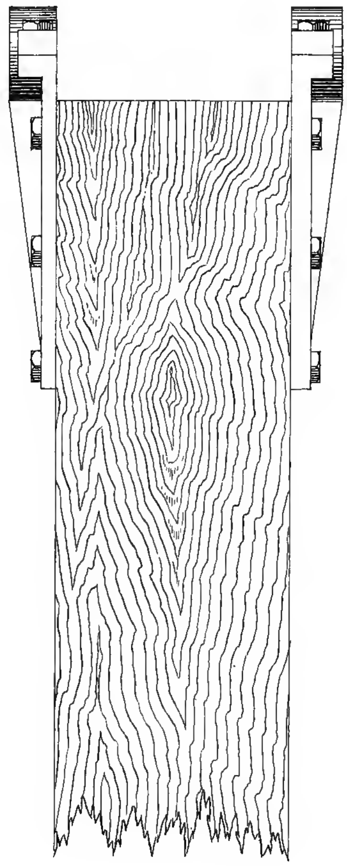


Fig. 41.

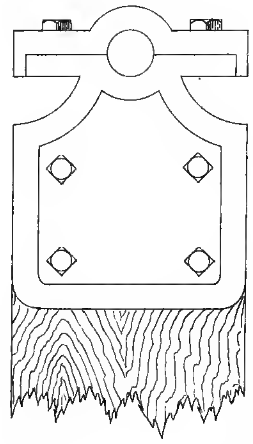


Fig. 42.

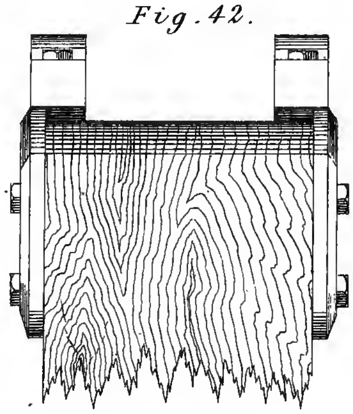


Fig. 43.

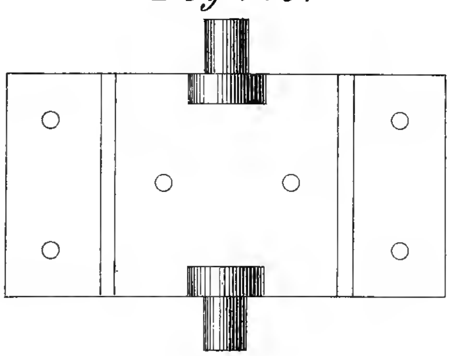


Fig 45.

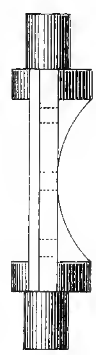


Fig. 46

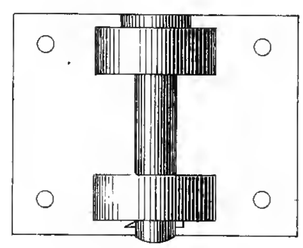


Fig. 47.

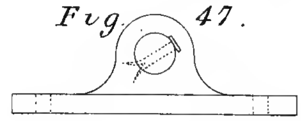


Fig 44.

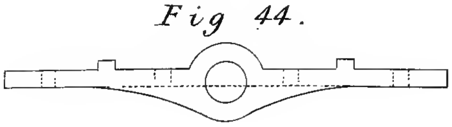
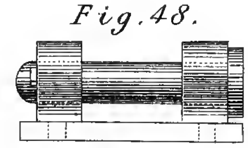


Fig. 48.



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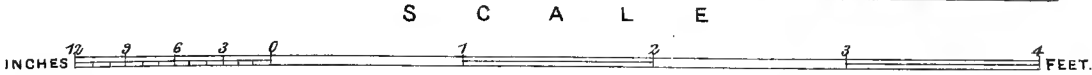
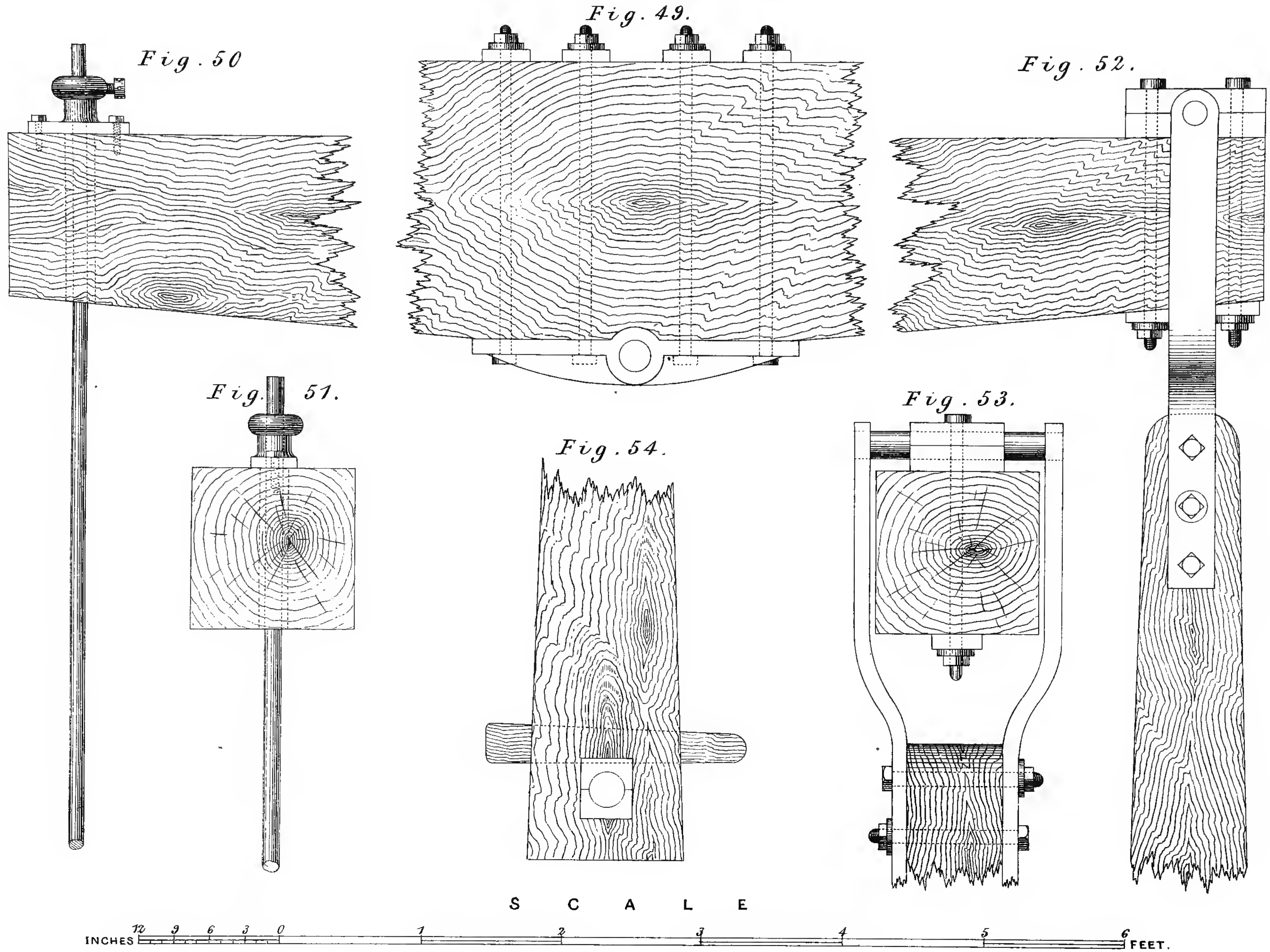


G.G. ANDRÉ.

E. & F. N. Spon. London & New York.

BORING APPARATUS — Details of Boring Frame.



G.G. ANDRÉ.

E & F.N Spon London & New York.

BORING APPARATUS — Band and Rope-pulley Wheels, and Details.

Fig. 55.

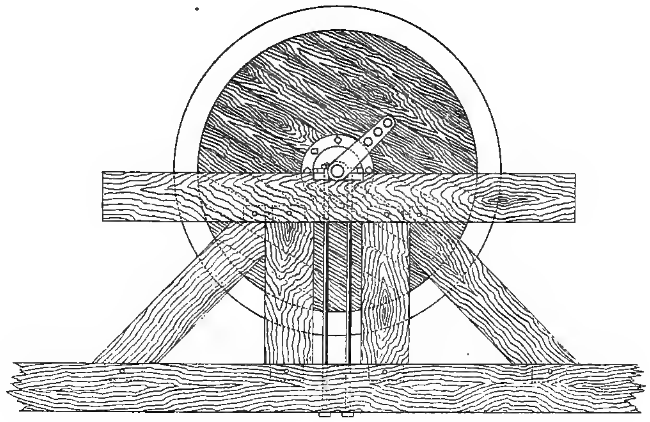


Fig. 56.

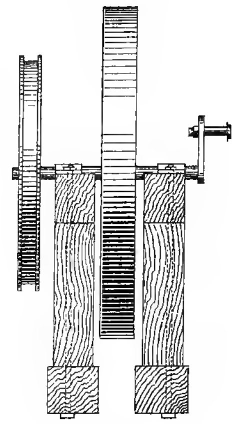


Fig. 57.

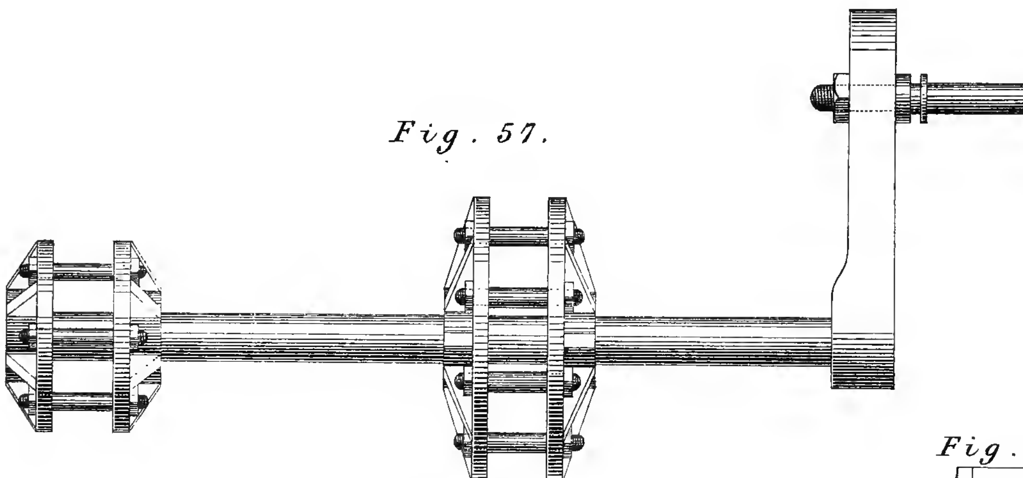


Fig. 58.

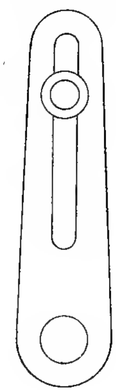


Fig. 59.

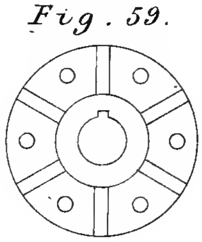


Fig. 60.

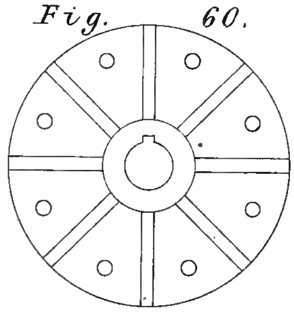


Fig. 61.

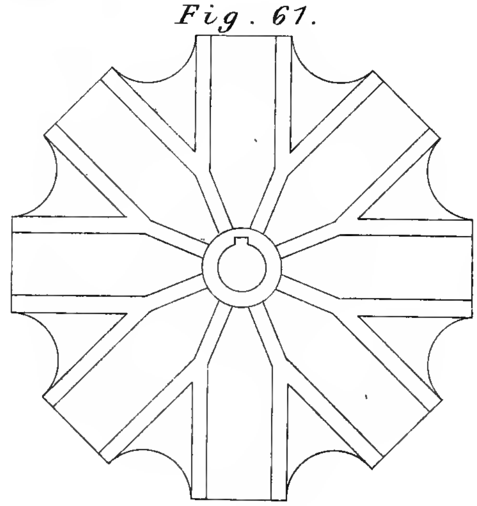
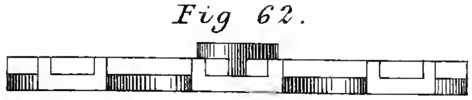


Fig 62.



SCALES.

FIGS. 57 TO 62.

INCHES 12 9 6 3 0 1 2 3 4 FEET.

FIGS. 55 & 56.

INCHES 12 6 0 1 2 3 4 5 6 7 8 9 10 FEET.

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BORING APPARATUS — Bull-wheel, Sand Pump Reel, and Details.

Fig. 63.

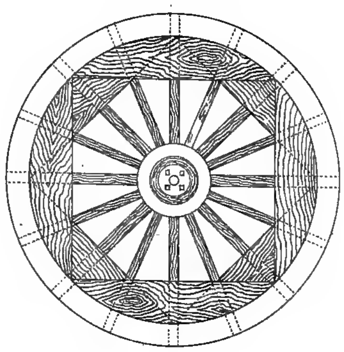


Fig 64.

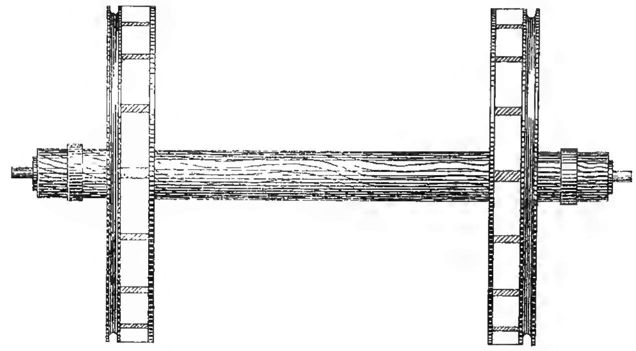


Fig 65

Fig. 66.

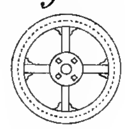


Fig. 67

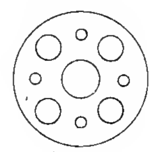


Fig. 68

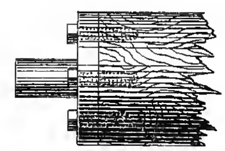


Fig. 69.

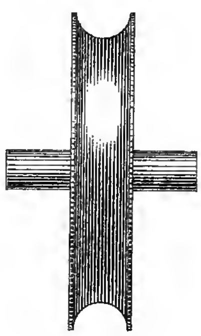


Fig 70.

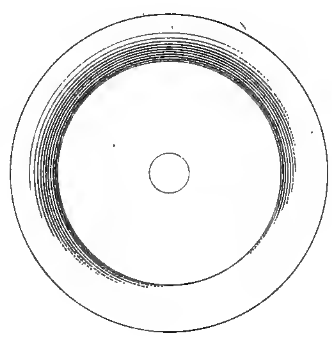


Fig. 71

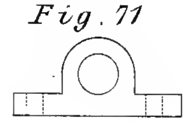


Fig. 72.

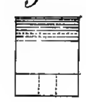


Fig 73.

Fig. 74.

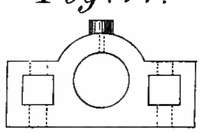


Fig 75.

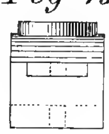


Fig. 78.

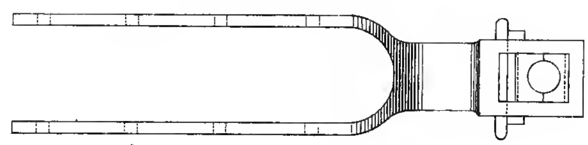


Fig. 76.

Fig 77.

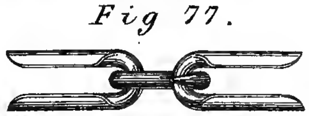
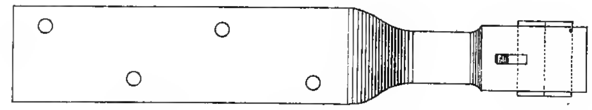


Fig. 79.



S C A L E S.

FIGS. 67 TO 79.

INCHES 12 9 6 3 0 1 2 3 4 FEET.

FIGS. 63 TO 66.

INCHES 12 6 0 1 2 3 4 5 6 7 8 9 10 FEET.

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Fig 80

BORING APPARATUS.

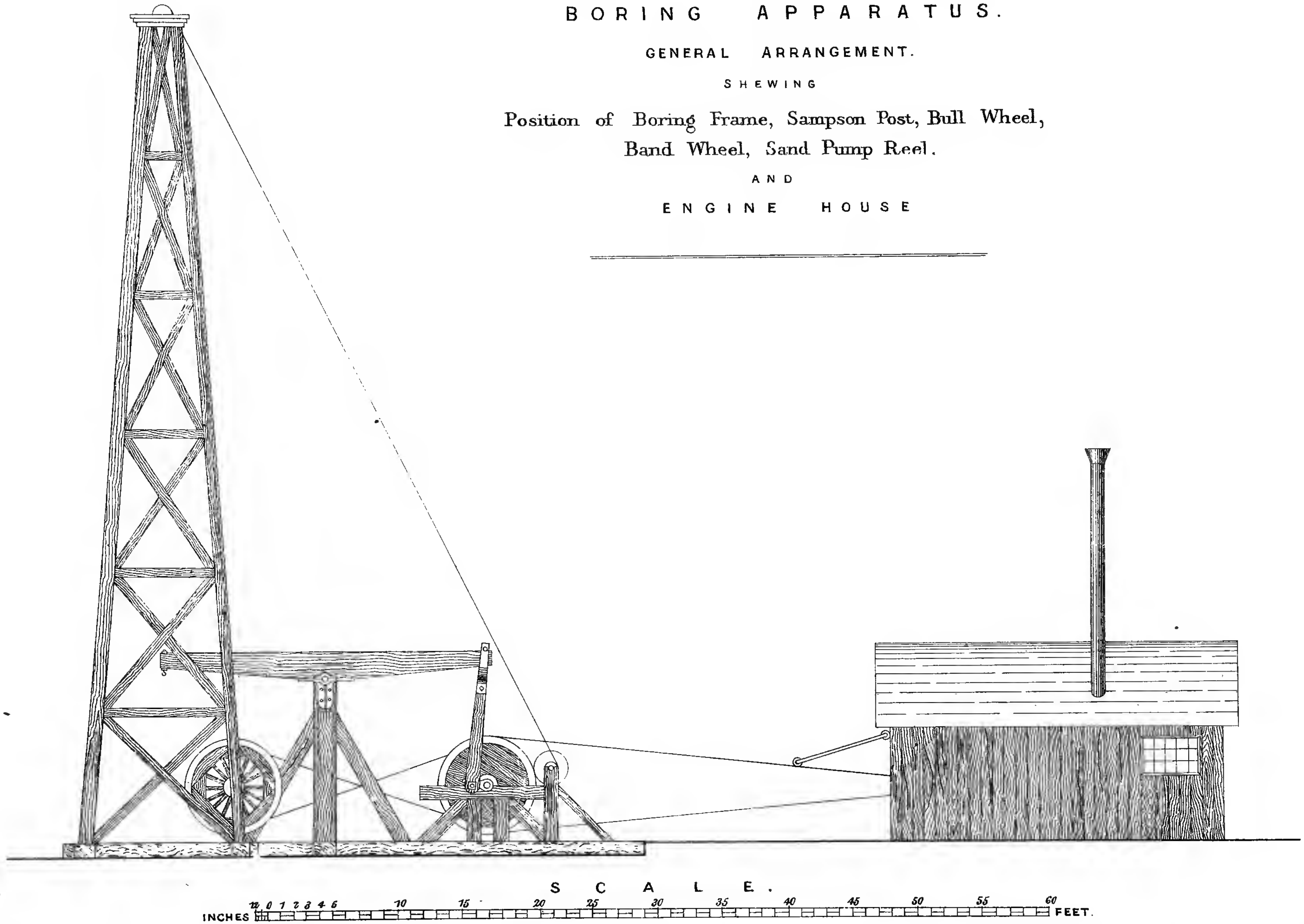
GENERAL ARRANGEMENT.

SHEWING

Position of Boring Frame, Sampson Post, Bull Wheel, Band Wheel, Sand Pump Reel.

AND

ENGINE HOUSE



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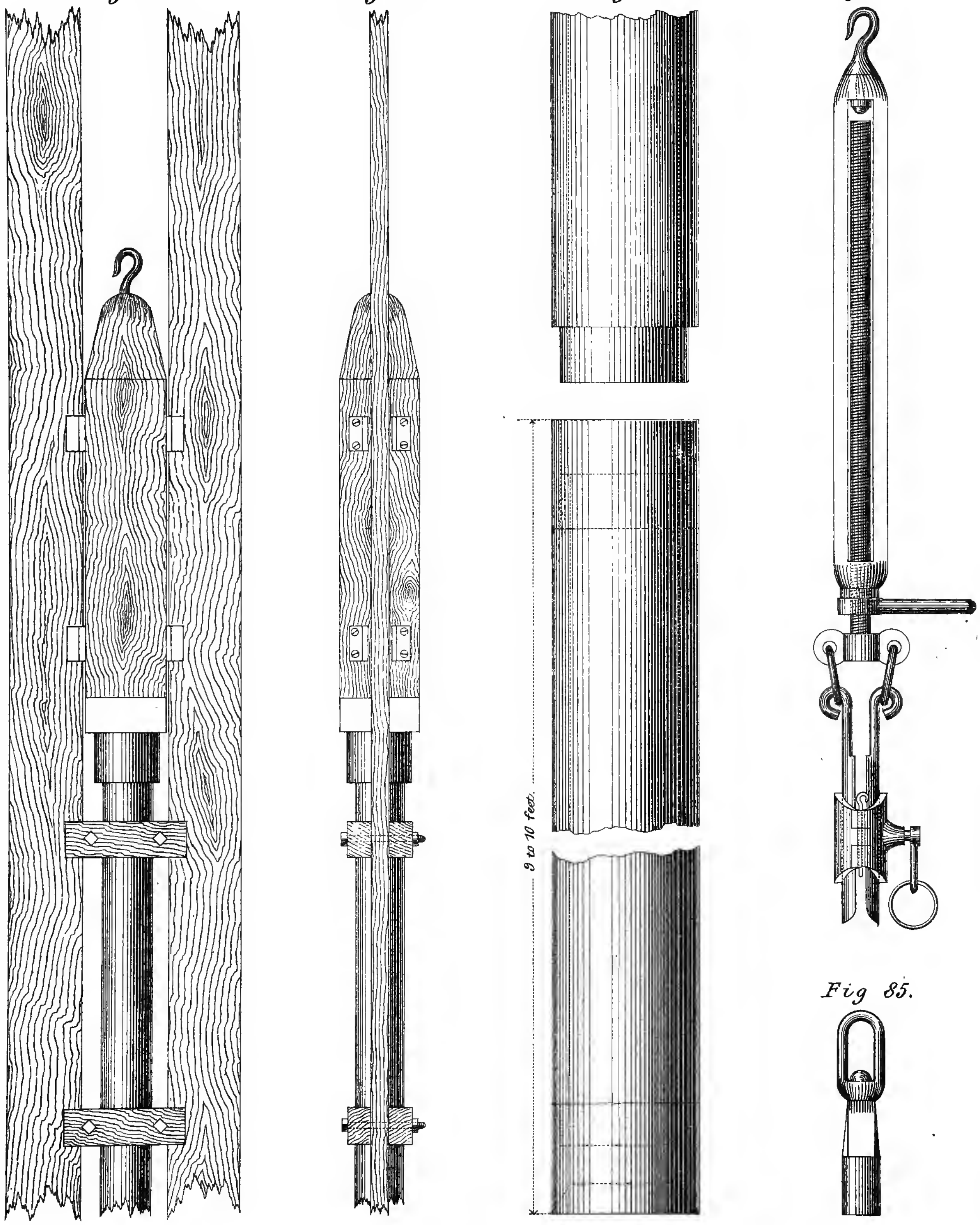
BORING APPARATUS — Battering Ram, Driving Pipe, Temper Screw, etc.

Fig. 81. Fig. 82. Fig. 83. Fig. 84.



SCALE.

FIGS. 81 & 82.

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 FEET.

FIGS. 83 TO 85.

INCHES 12 9 6 3 0 1 2 FEET.

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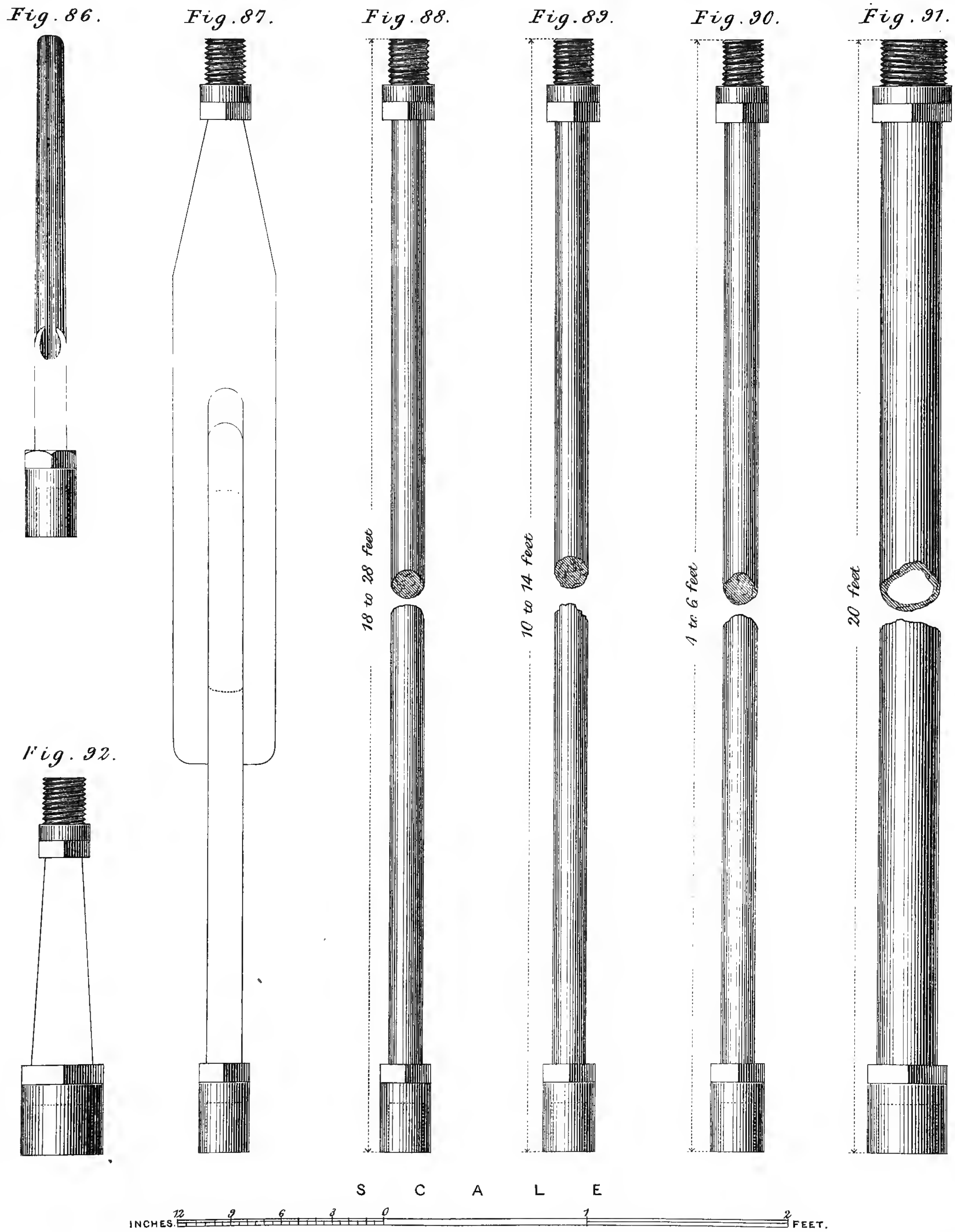
BORING APPARATUS — Connections, and Pole Tool Rods.



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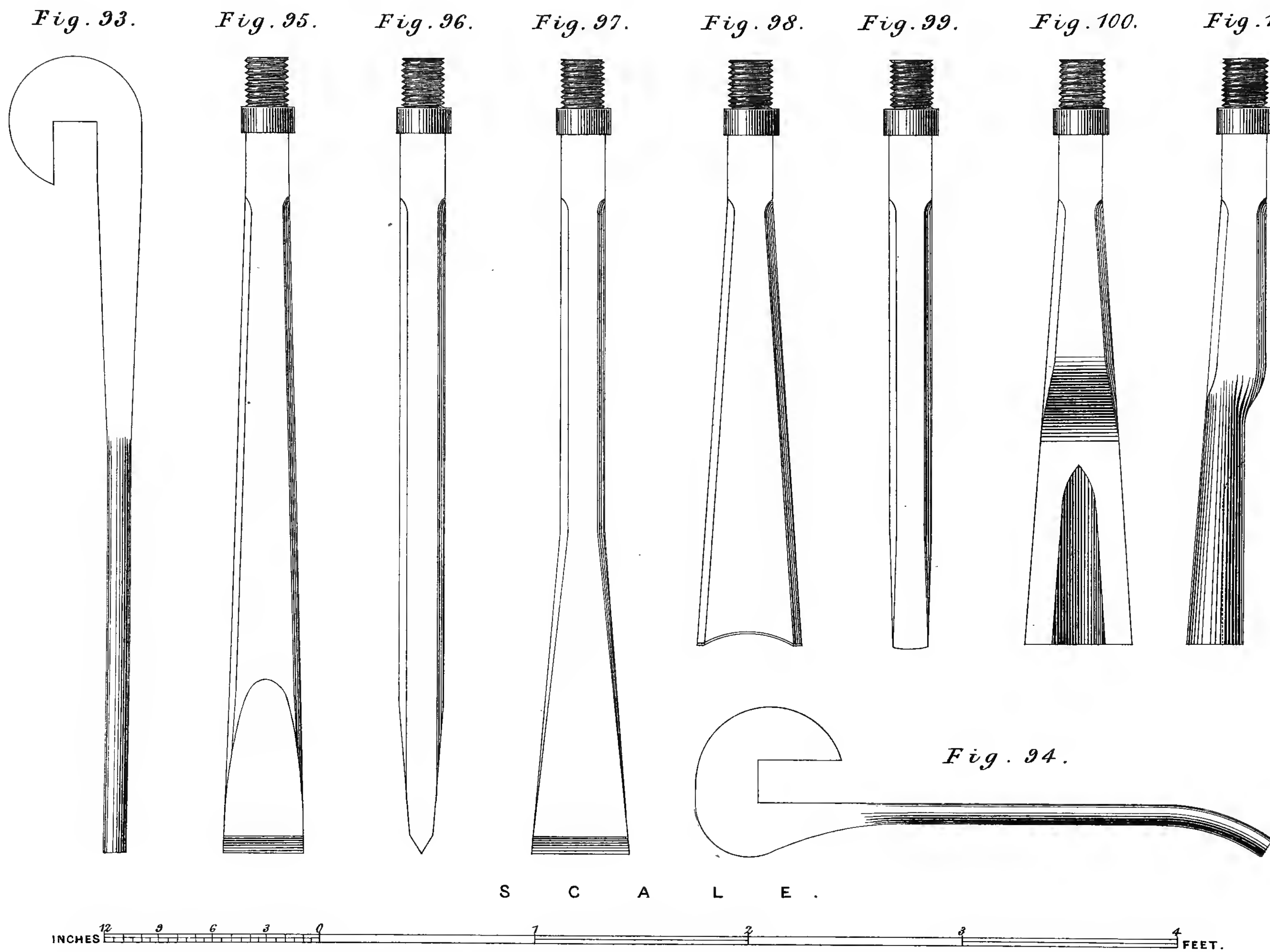
BORING APPARATUS — Wrenches, and Cutting Tools.



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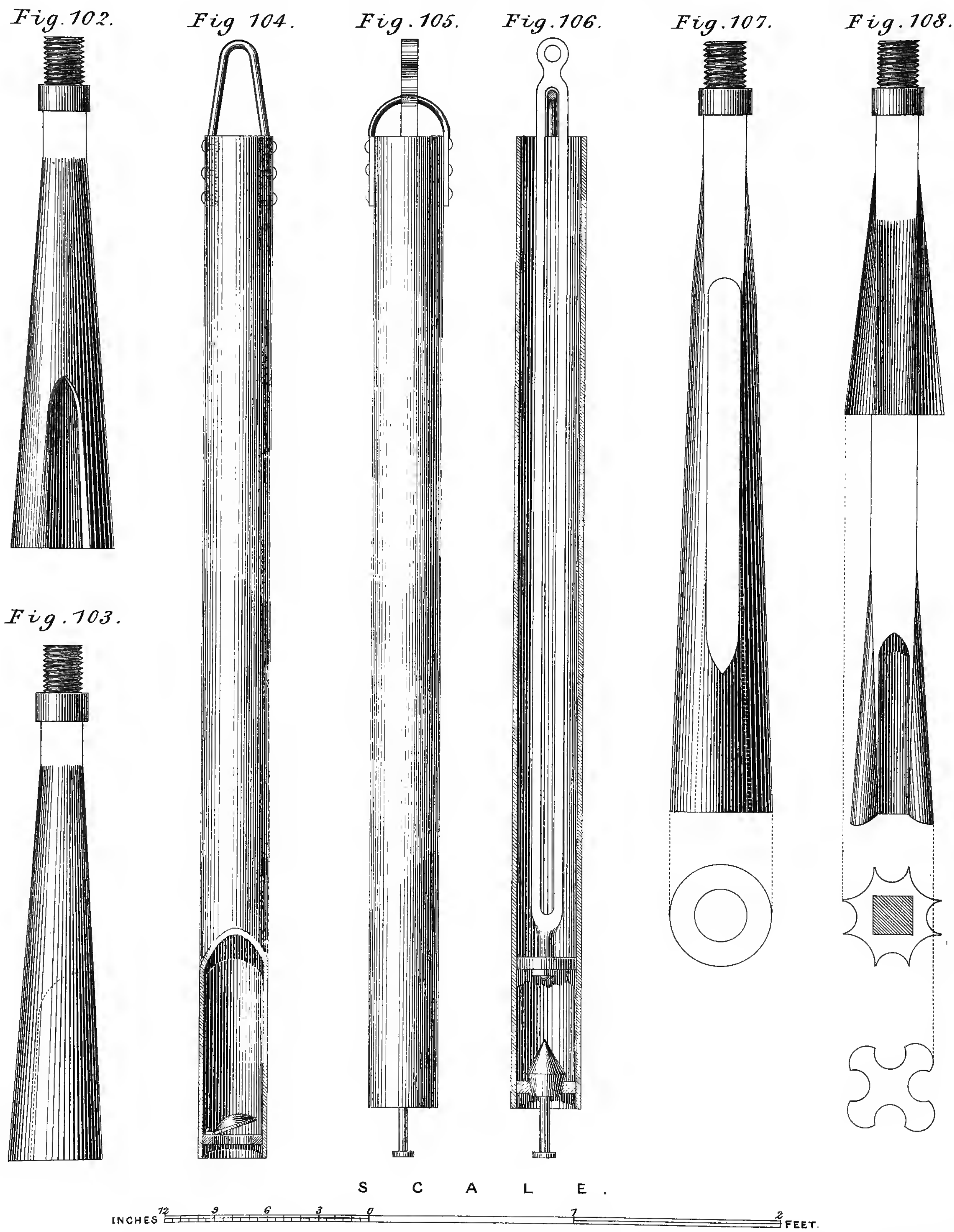
BORING APPARATUS — Cutting, Clearing, and Regulating Tools.



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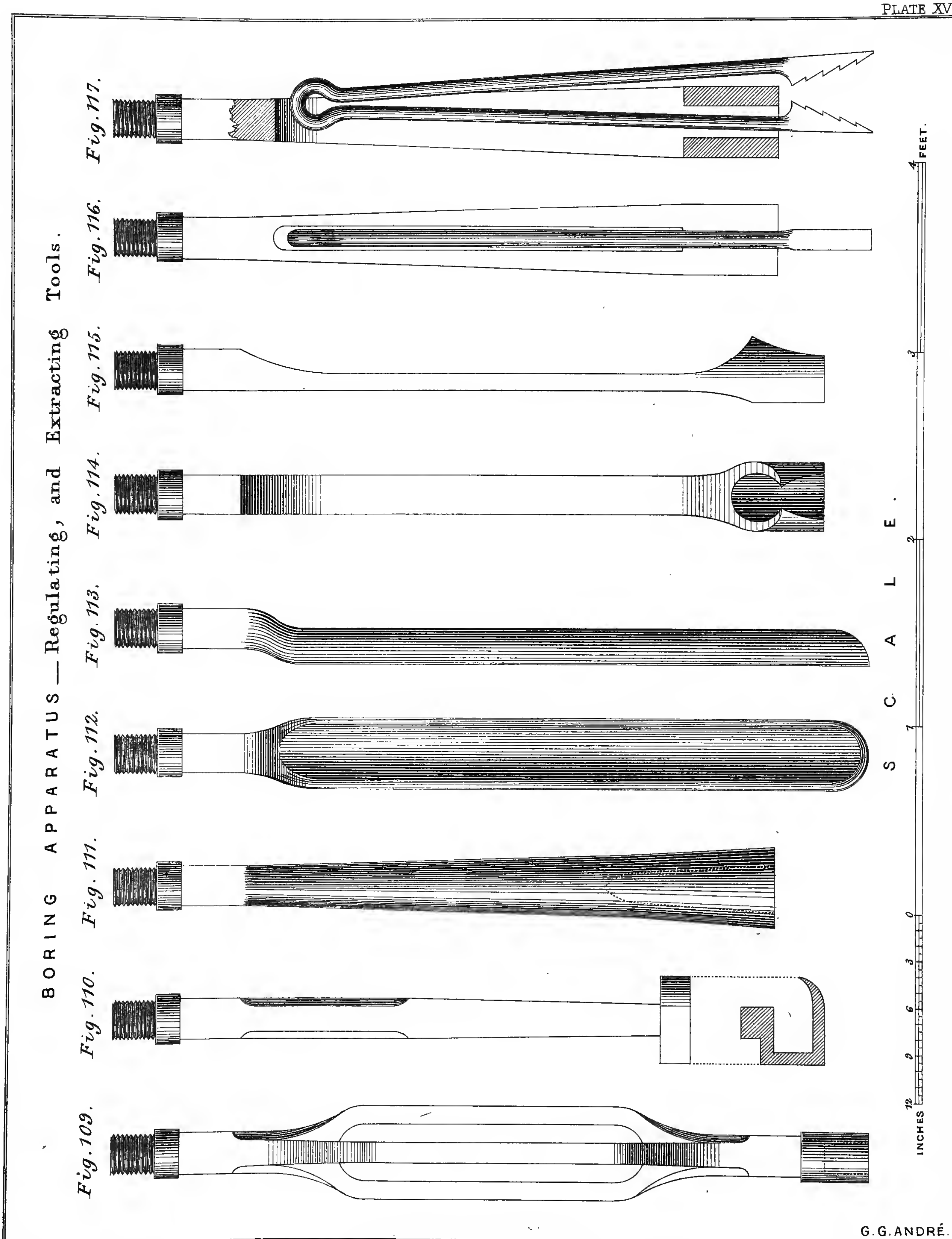

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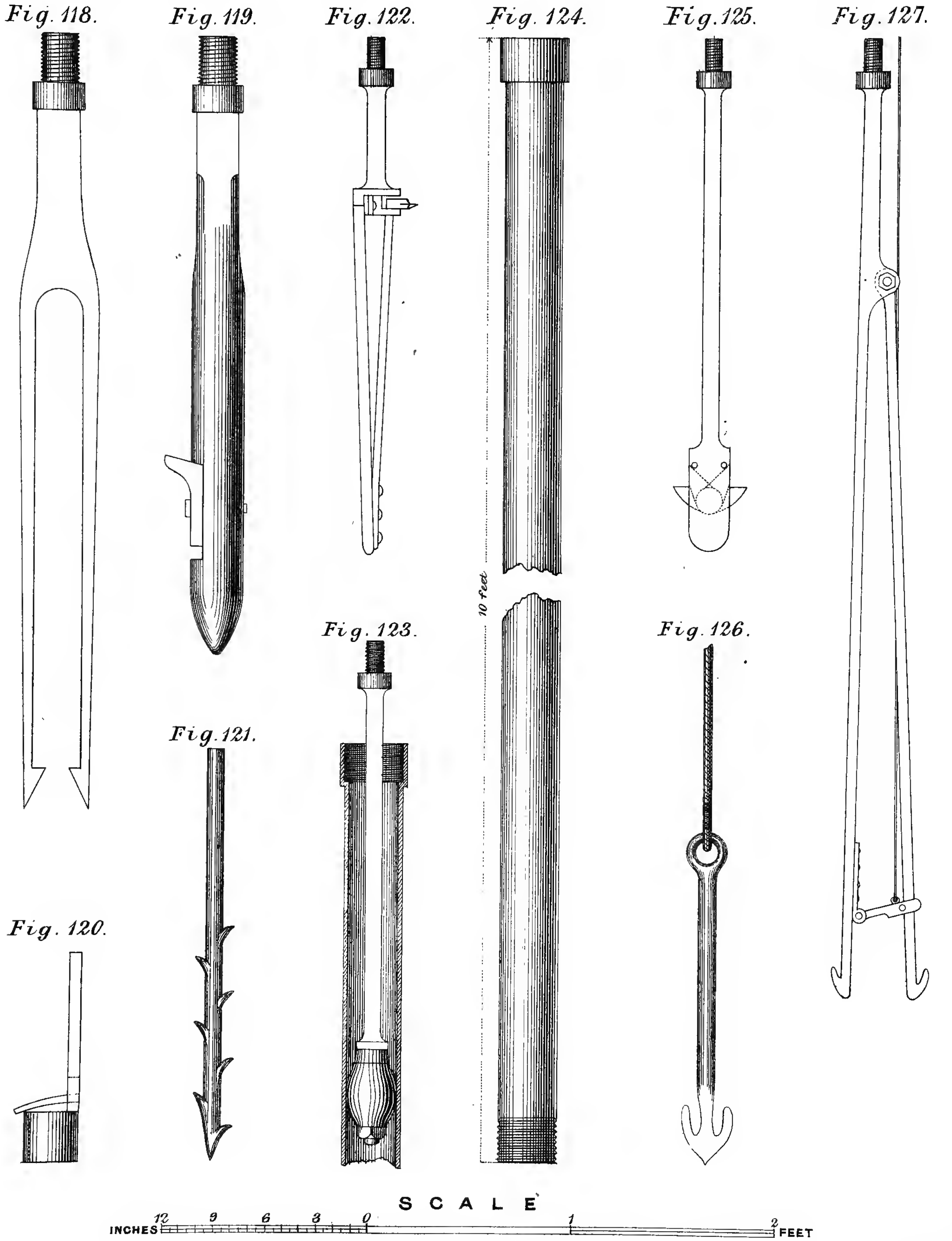
BORING APPARATUS. Extracting Tools, Lining Tubes, etc.



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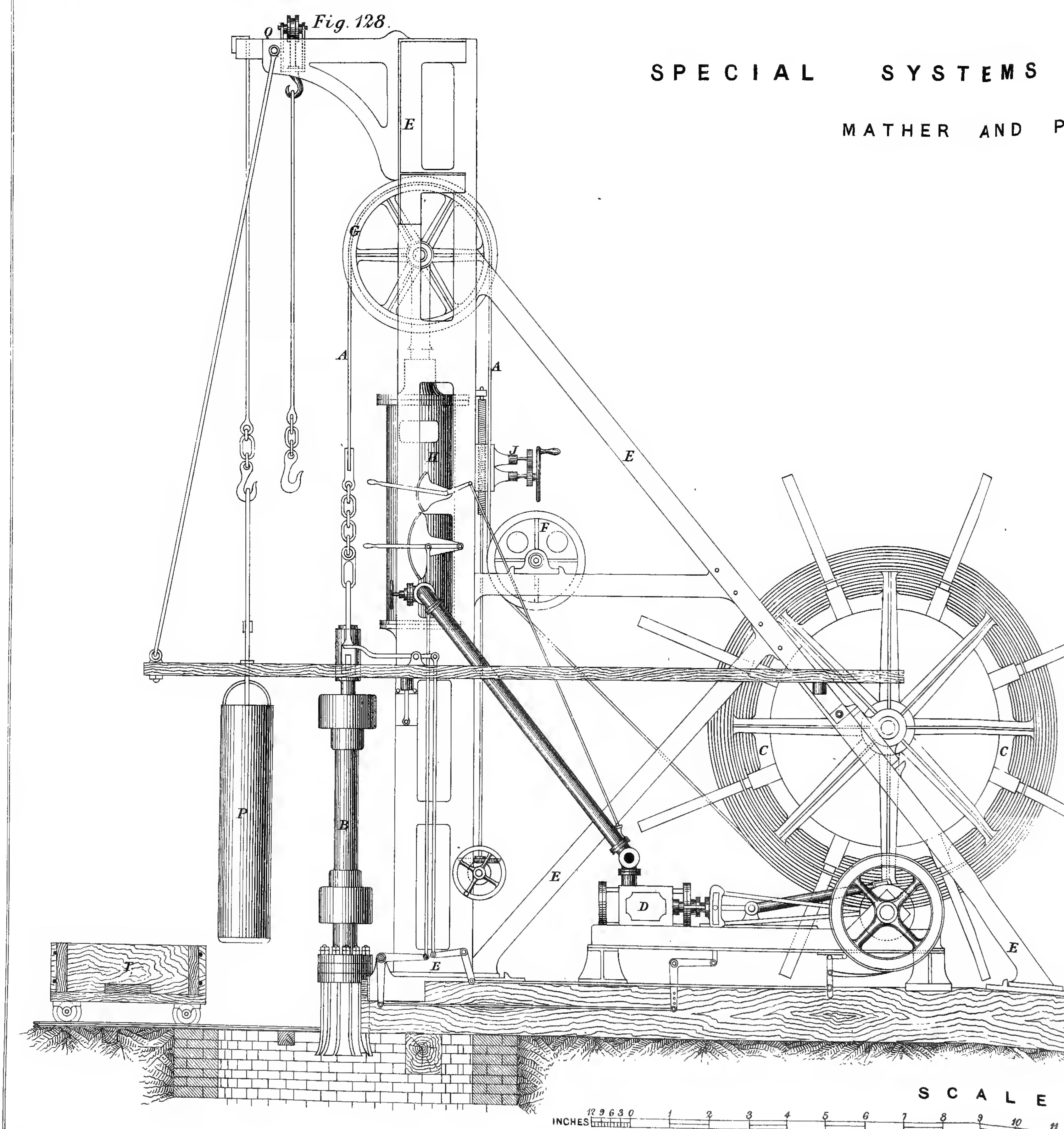
SPECIAL SYSTEMS

MATHER AND P

Fig. 128.



SCALE

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EMS OF BORING.

AND PLATT.

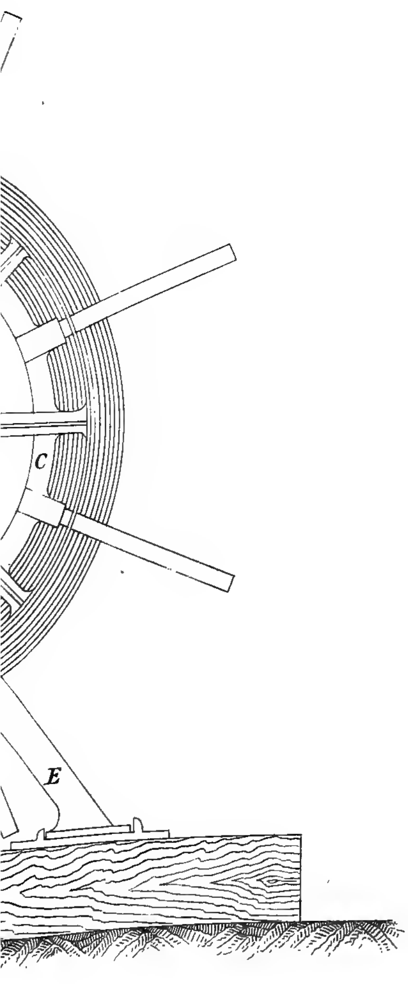
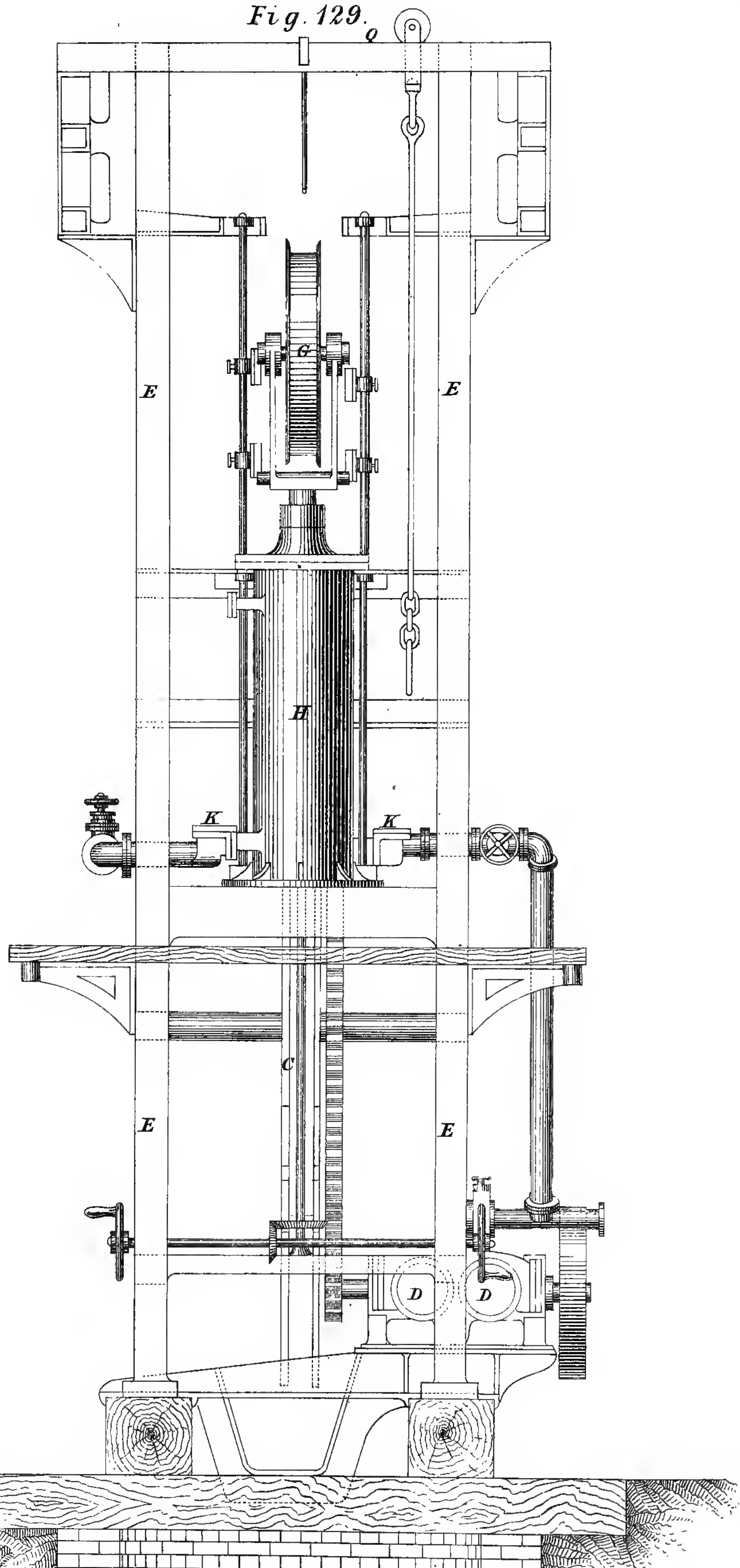


Fig. 129.



ALE.

10 11 12 13 14 15 16 17 18 FEET

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MATHER AND PLATT'S BORING APPARATUS — Cutting and Extracting Tools.

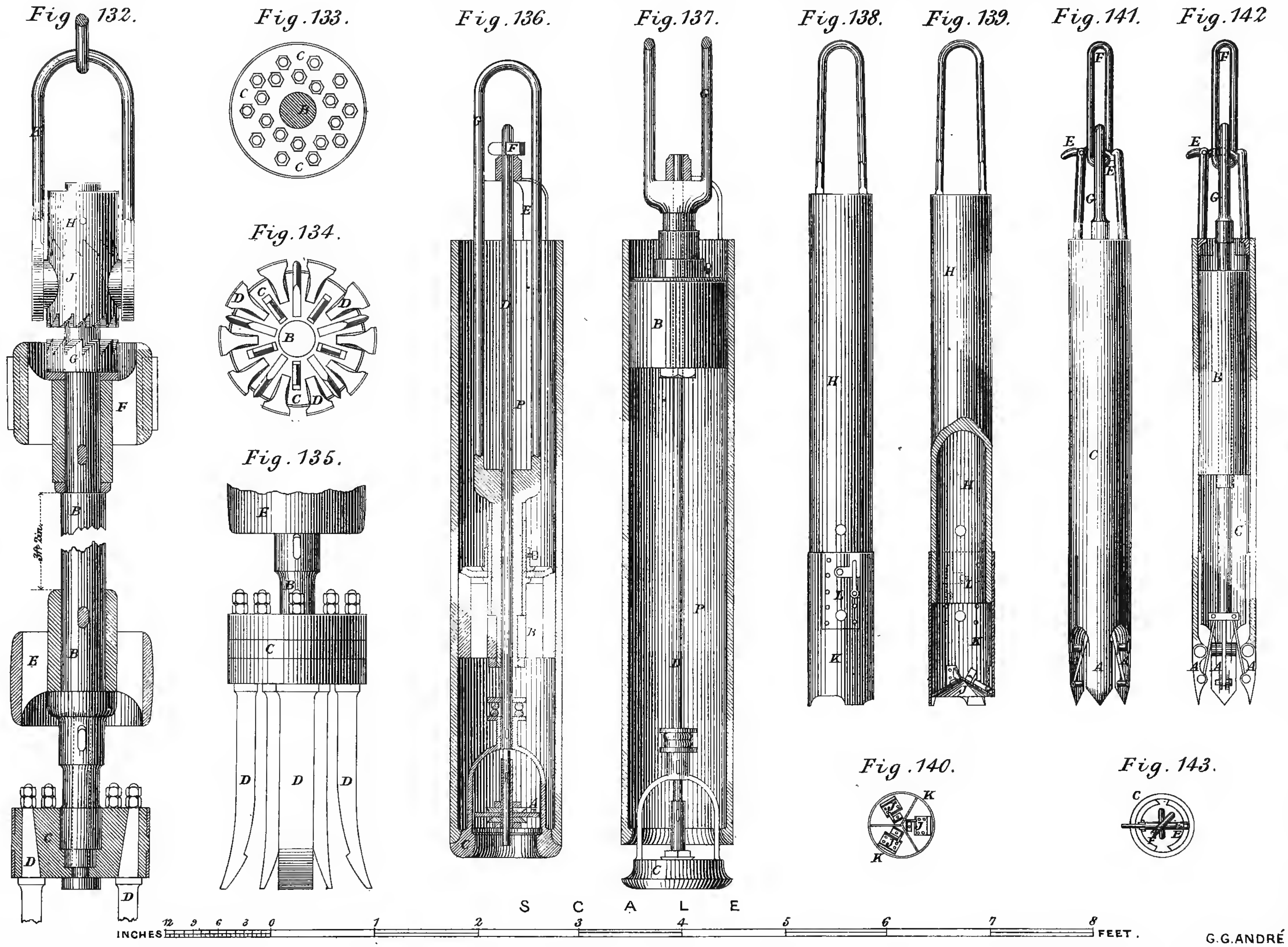

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Plate XX.

MATHER AND PLATT'S BORING APPARATUS — Details.

Fig. 130.

Fig. 131.

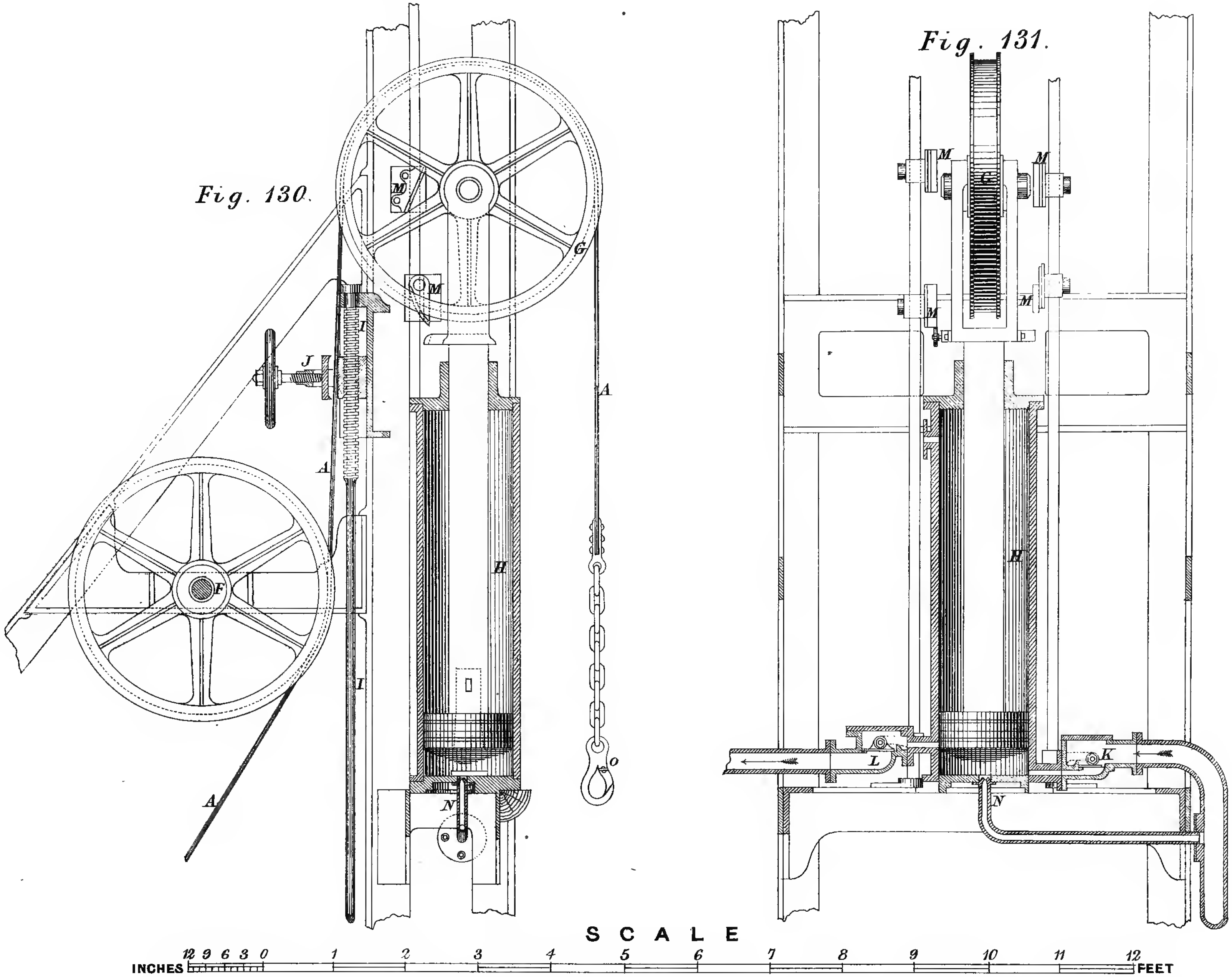

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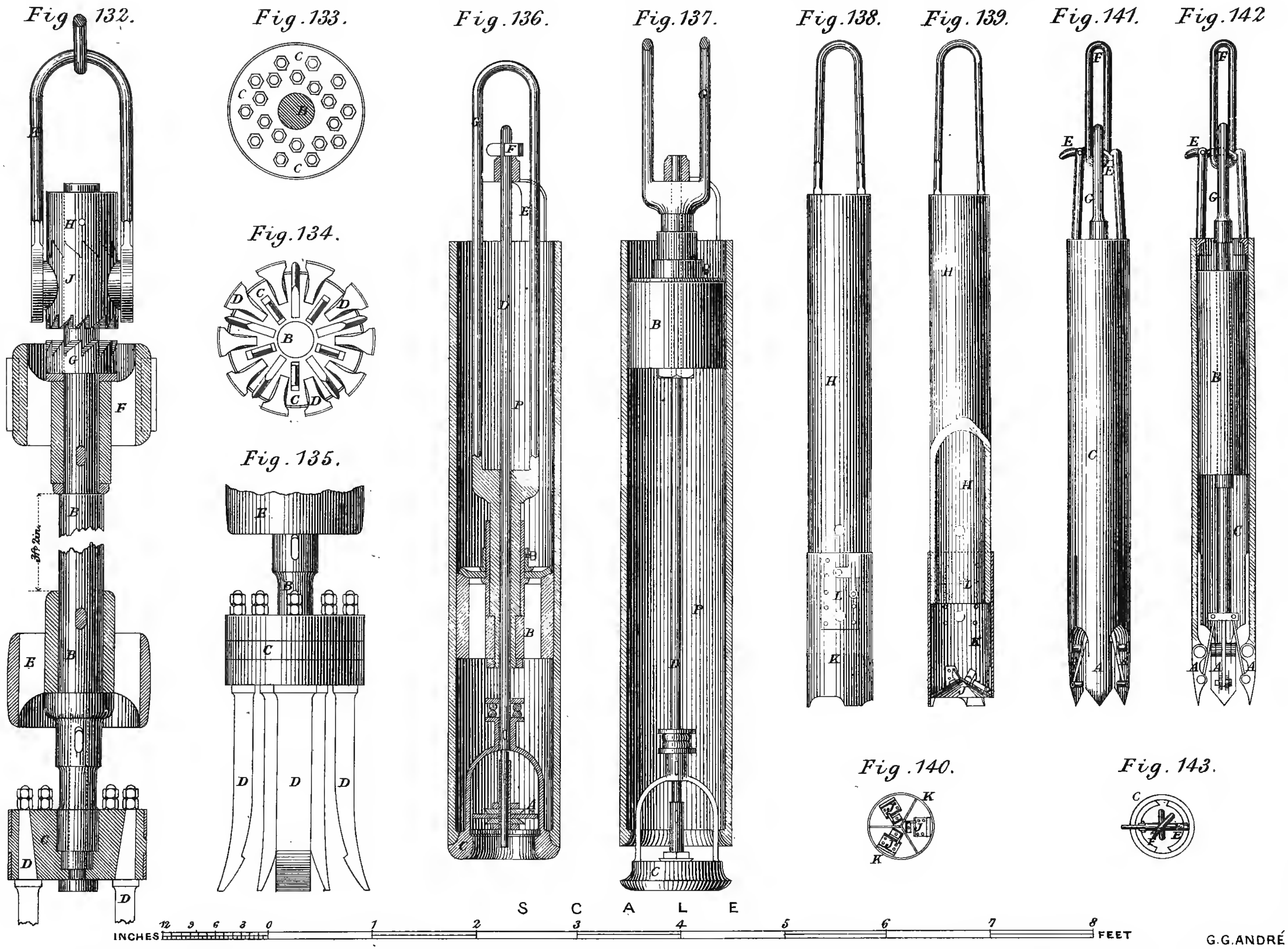
PLATE XXI.

MATHER AND PLATT'S BORING APPARATUS — Cutting and Extracting Tools.



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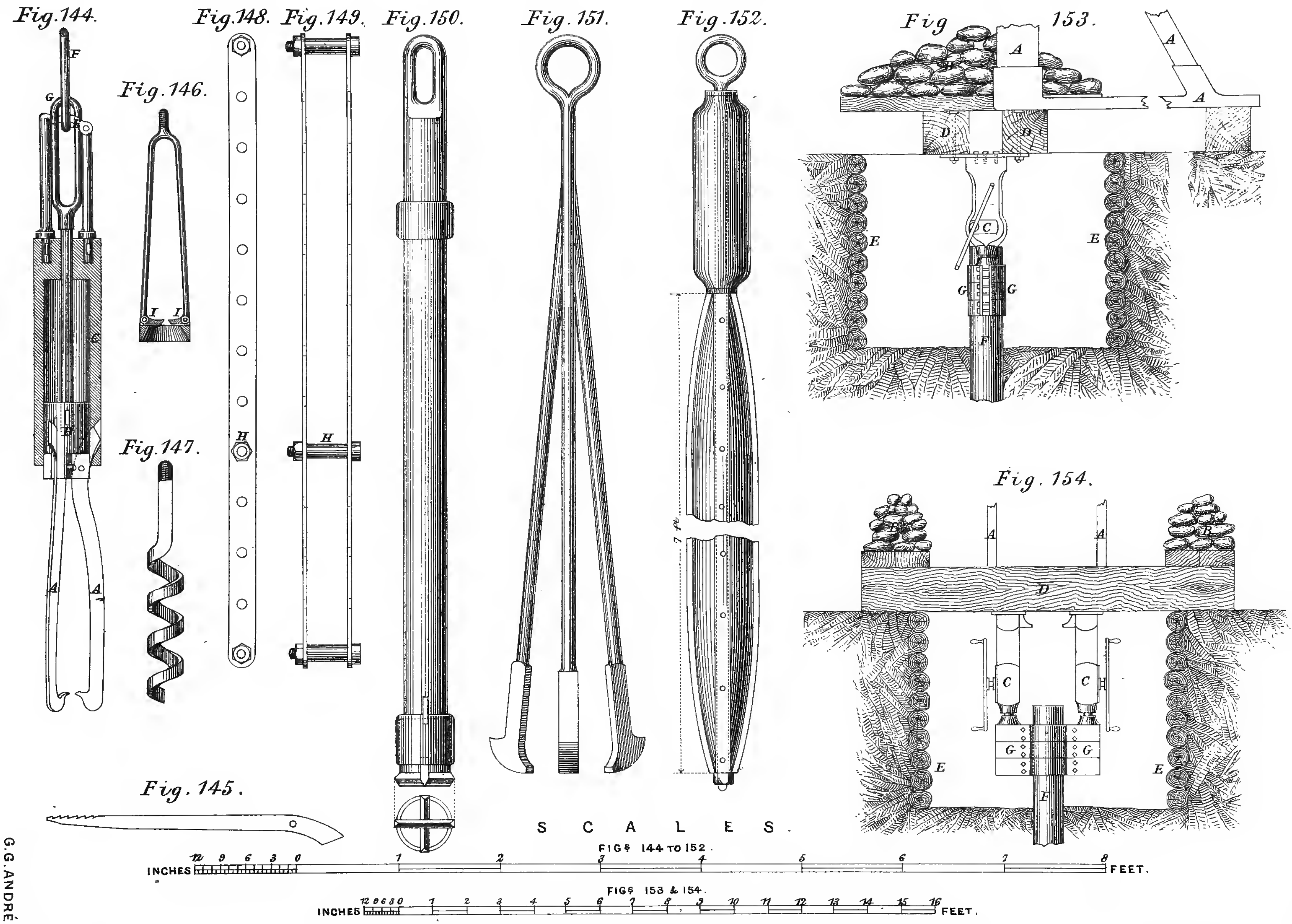
MATHER AND PLATT'S BORING APPARATUS — Accident Tools and Tube-Forcing Apparatus.



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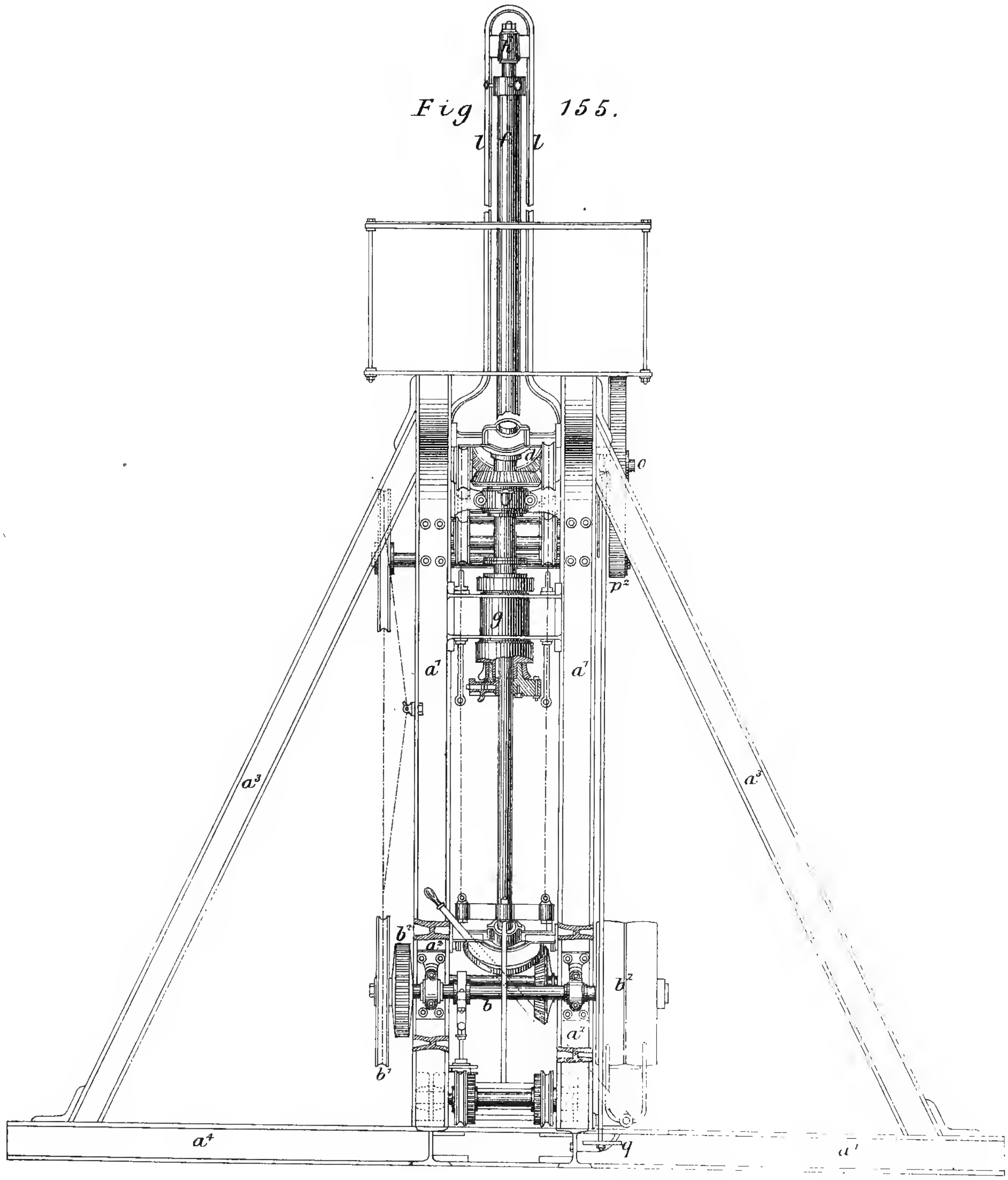
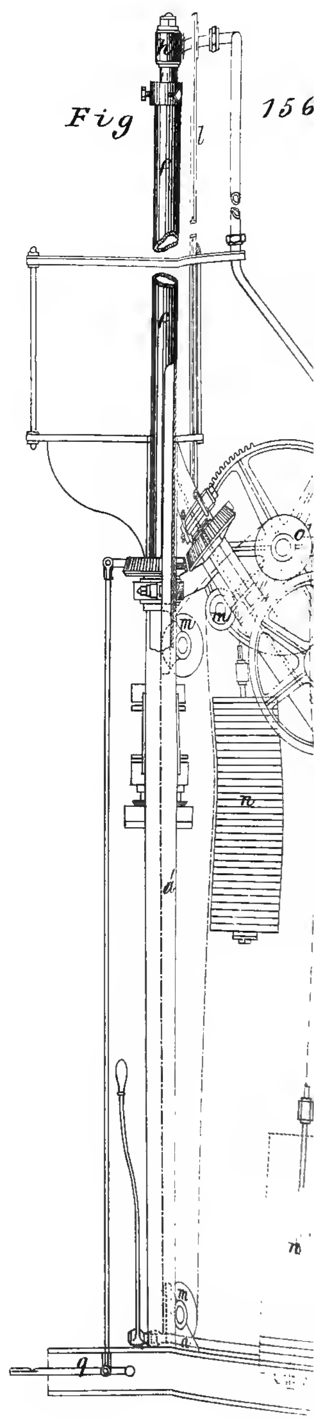
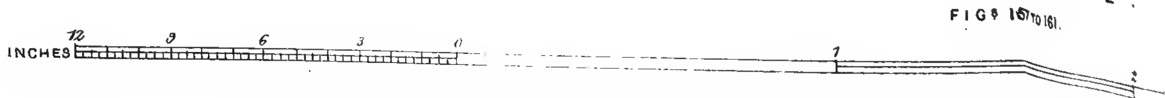
DIAMOND ROCK-BORING





SCALE.

FIGS 157 TO 161.



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G APPARATUS.

156.

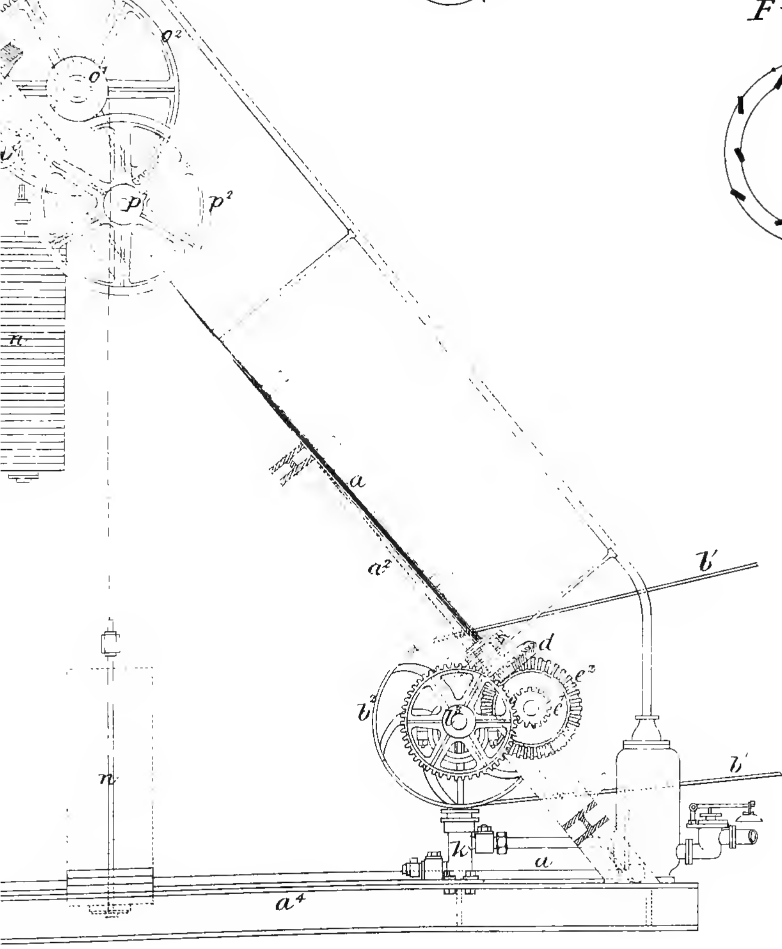


Fig. 157.

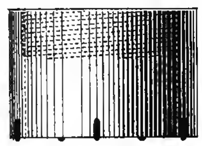


Fig. 159.

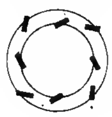


Fig. 158.

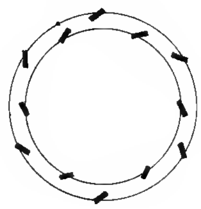


Fig. 160.

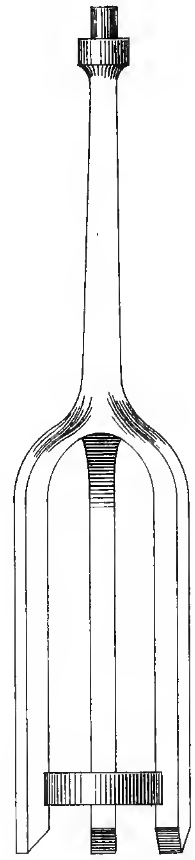
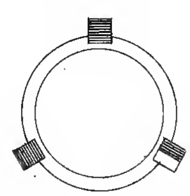


Fig. 161



E .

2 3 4 FEET.

G.G.ANDRÉ.

York.

HAND BORING TOOLS — Drills and Sledges.

Fig. 162.

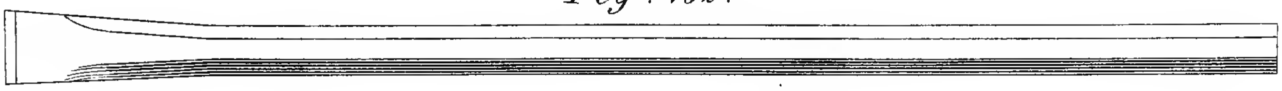


Fig 163.

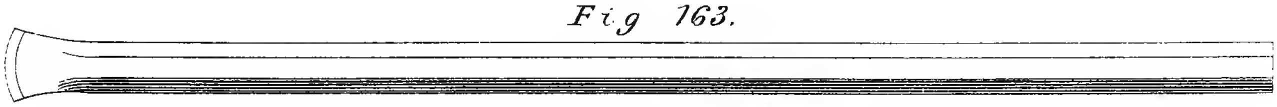


Fig. 164.

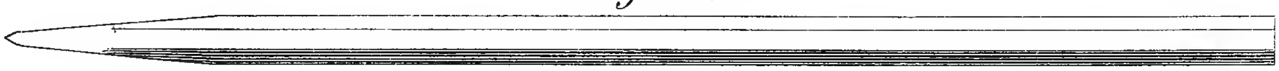


Fig. 165.

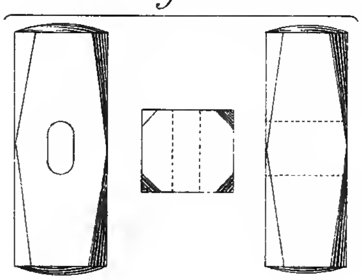


Fig. 166.

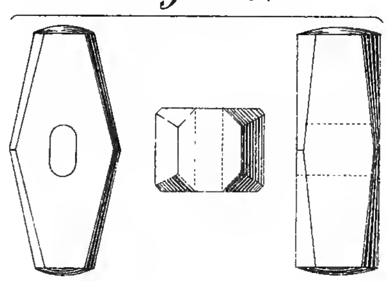


Fig. 167.

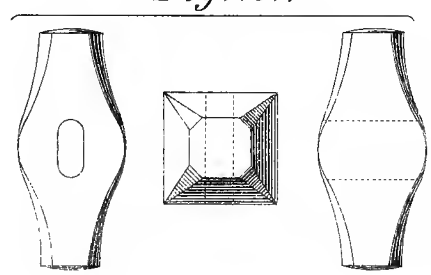


Fig. 169.

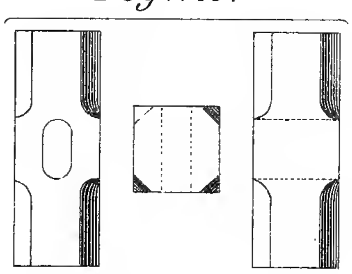


Fig. 170.

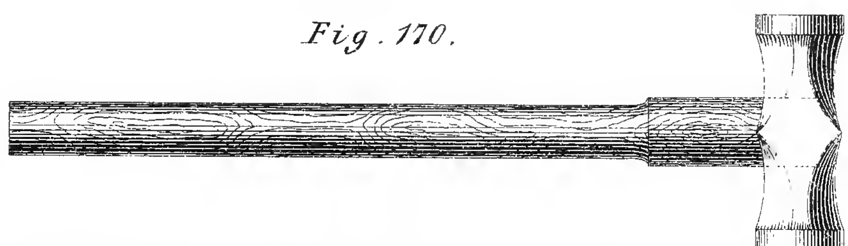


Fig. 171.

Fig. 168.

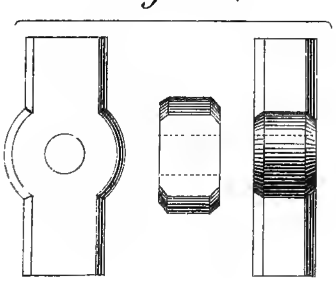
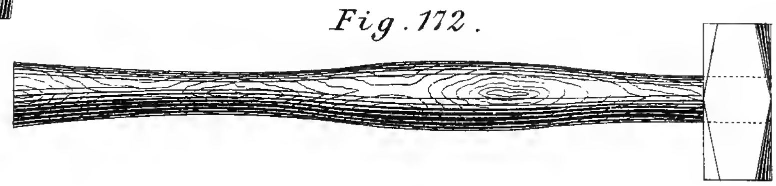
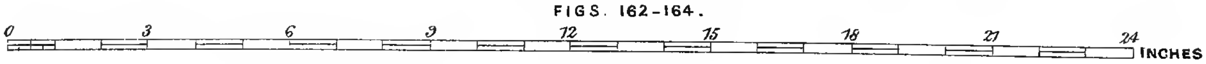


Fig. 172.

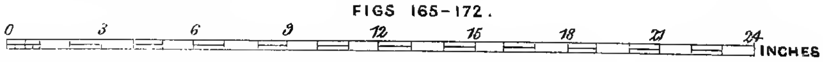


S C A L E S.

FIGS. 162-164.



FIGS 165-172.



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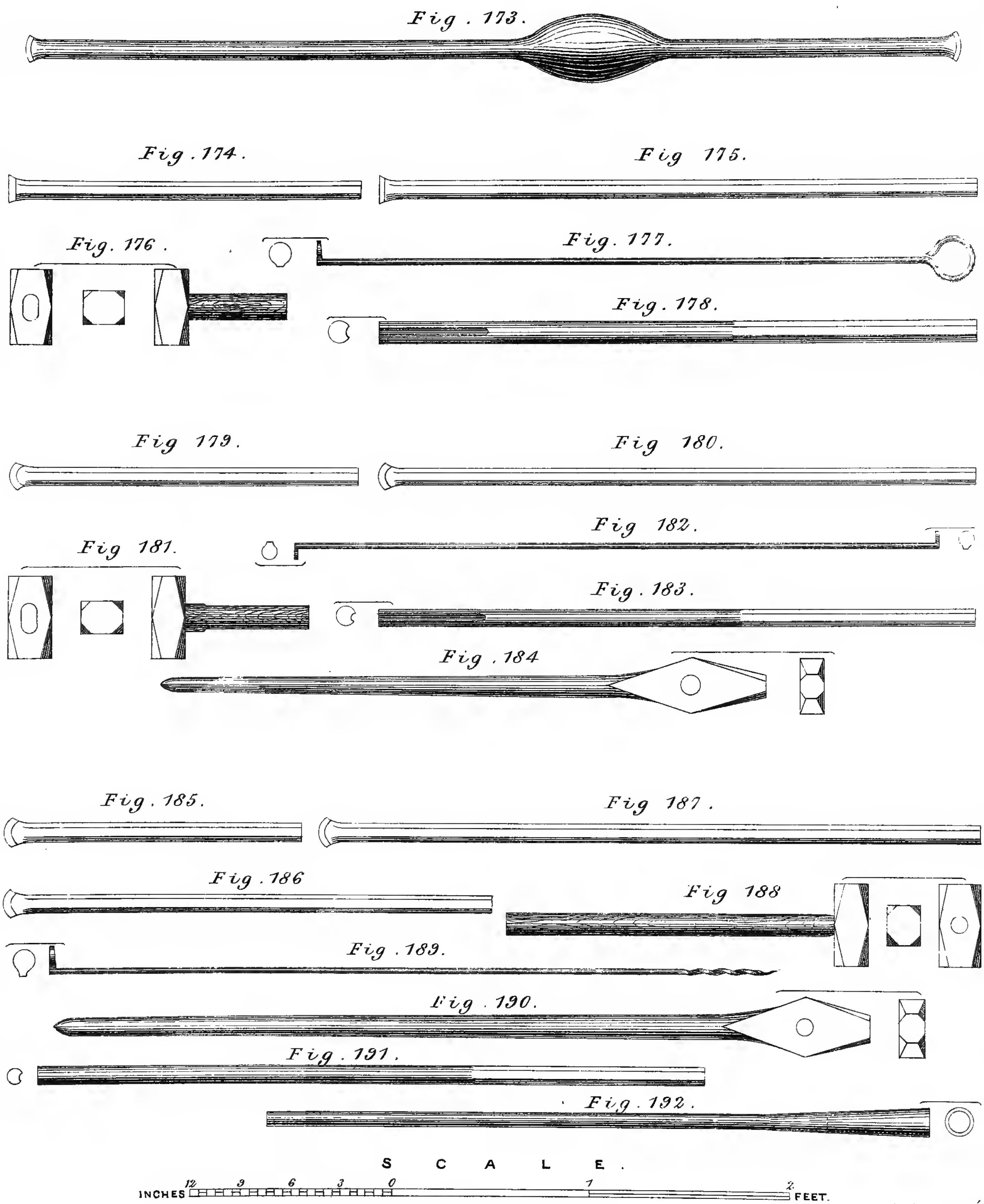
HAND BORING TOOLS — Jumper, Drills, Hammers, etc.



G. G. ANDRÉ.

E & F. N. Spon. London & New York.

ROCK-BORING MACHINES

Fi

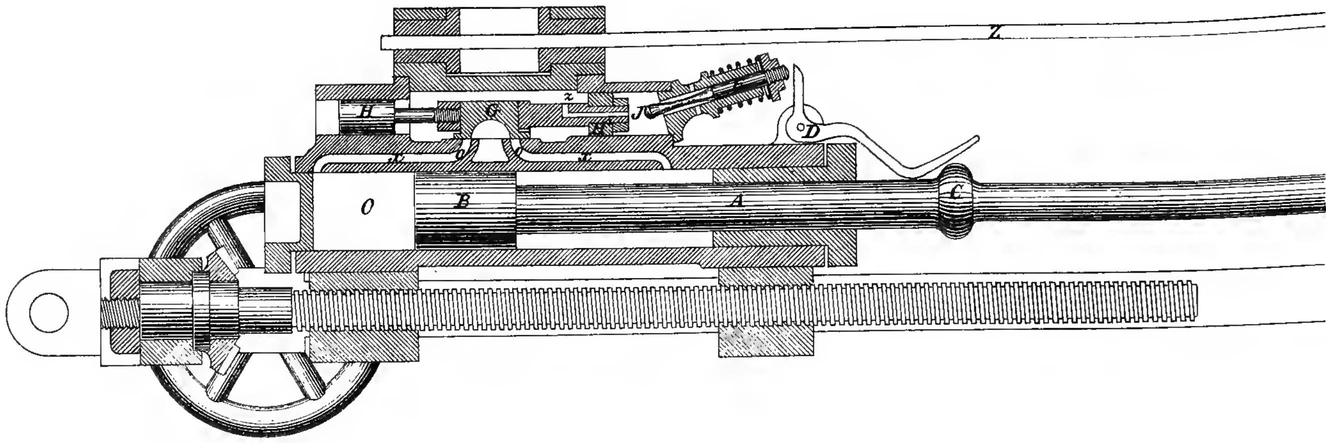
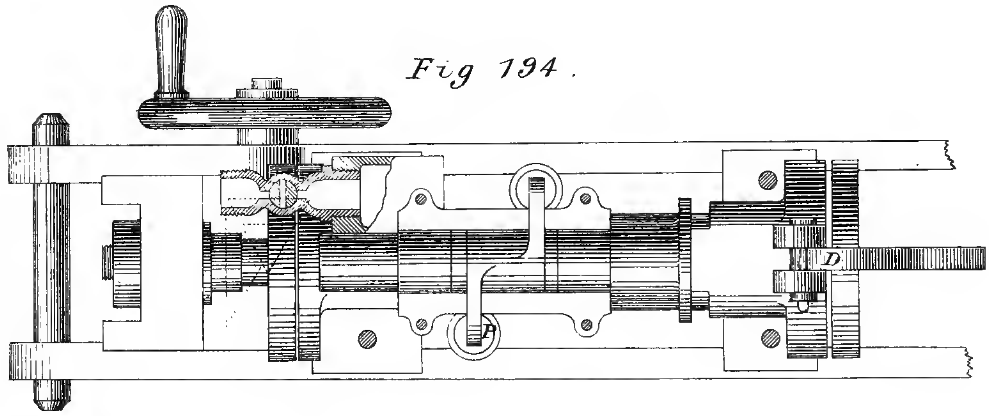
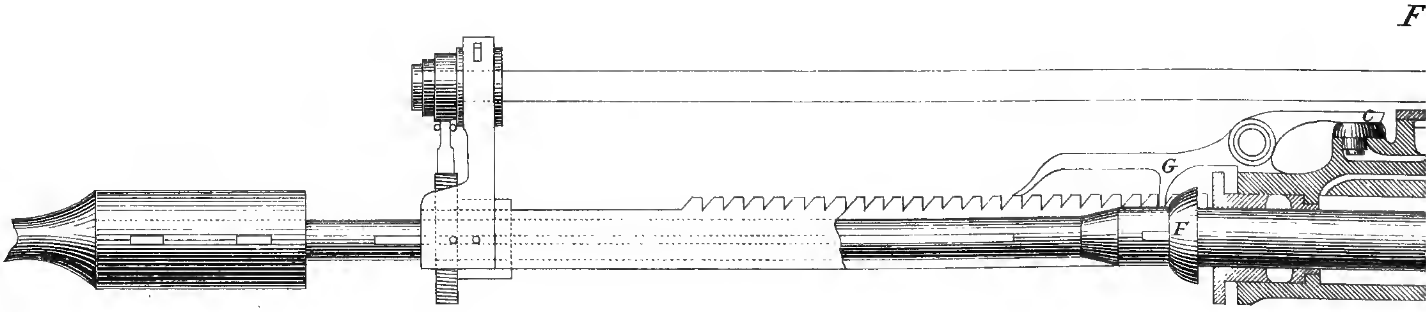


Fig 194.



F



S C

FI

INCHES 12 9 6 3 0 1

INCHES 12 9 6 3 0 1 2 3

E & F.N. Sp

ES — DUBOIS-FRANCOIS AND FERROUX

Fig. 193.

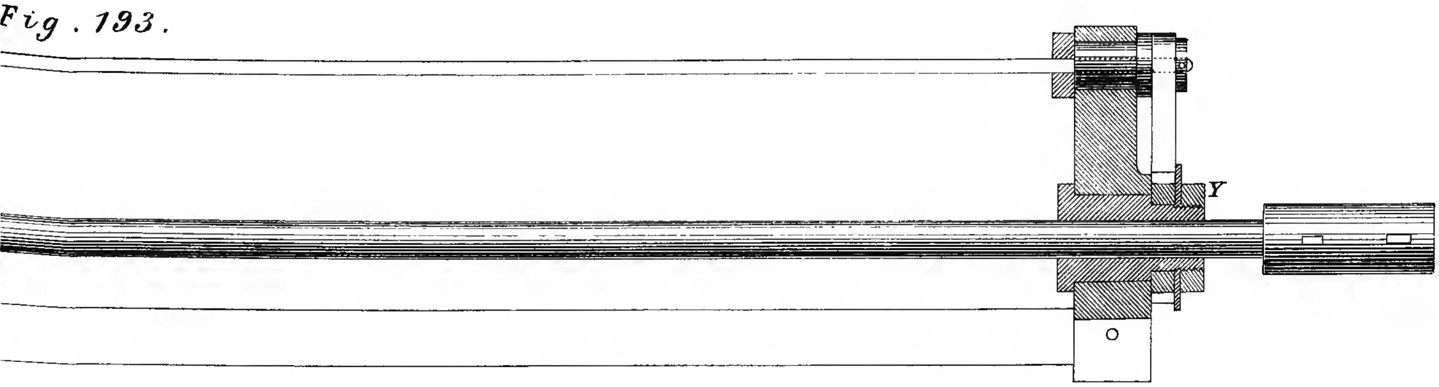


Fig. 195.

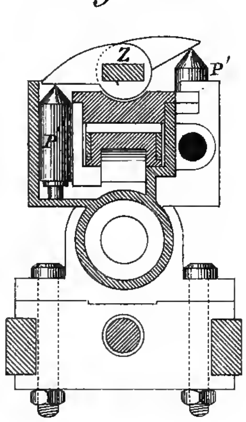


Fig 196.

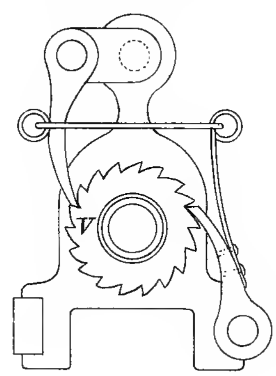
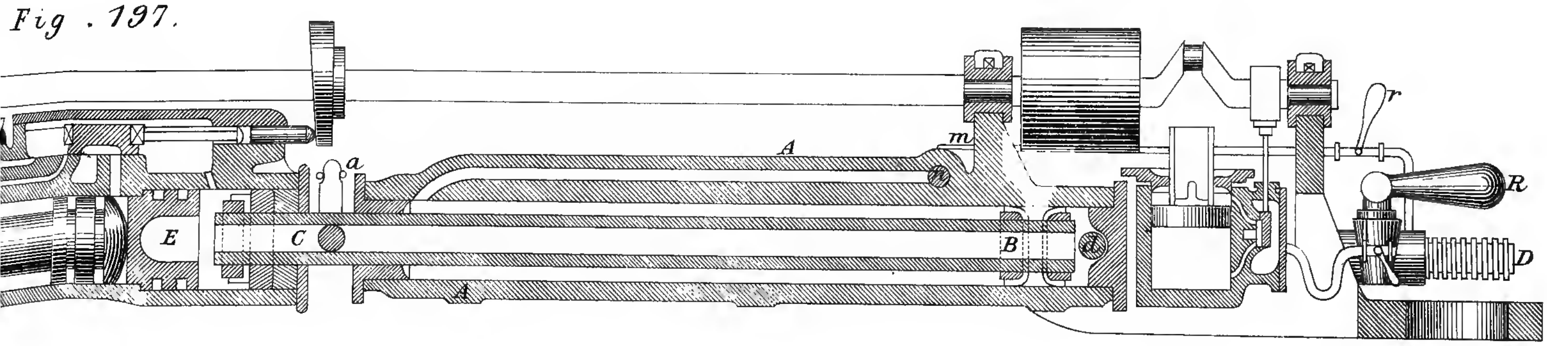


Fig. 197.



A L E S.

FIGS. 193 – 196.

2 3 4 FEET

FIG. 197.

4 5 6 7 8 FEET.

G.G. ANDRÉ.

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ROCK-BORING MACHINES — BURLEIGH & MAC KEAN.

Fig 198.

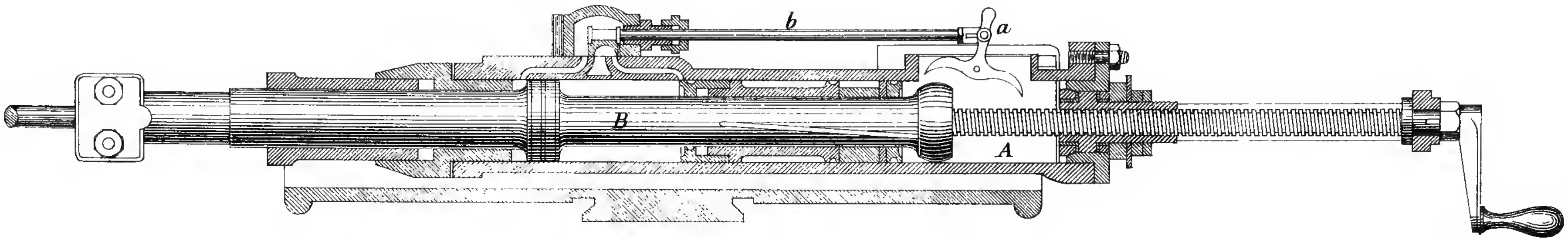


Fig 199.

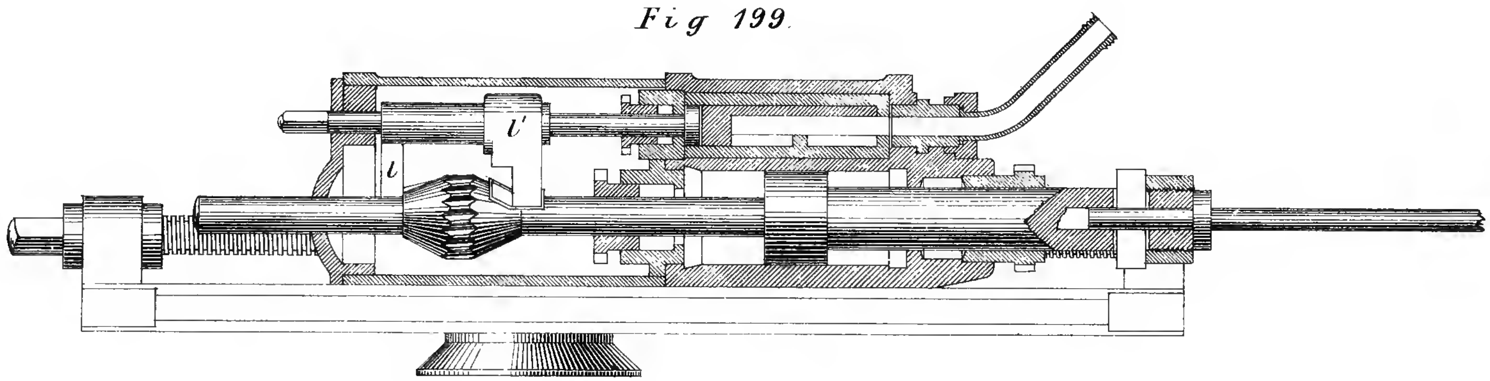
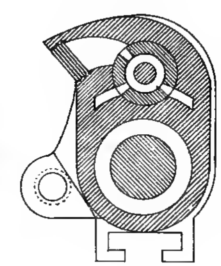


Fig. 200.



SCALE

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ROCK-BORING MACHINES — INGERSOLL.

Fig. 201.

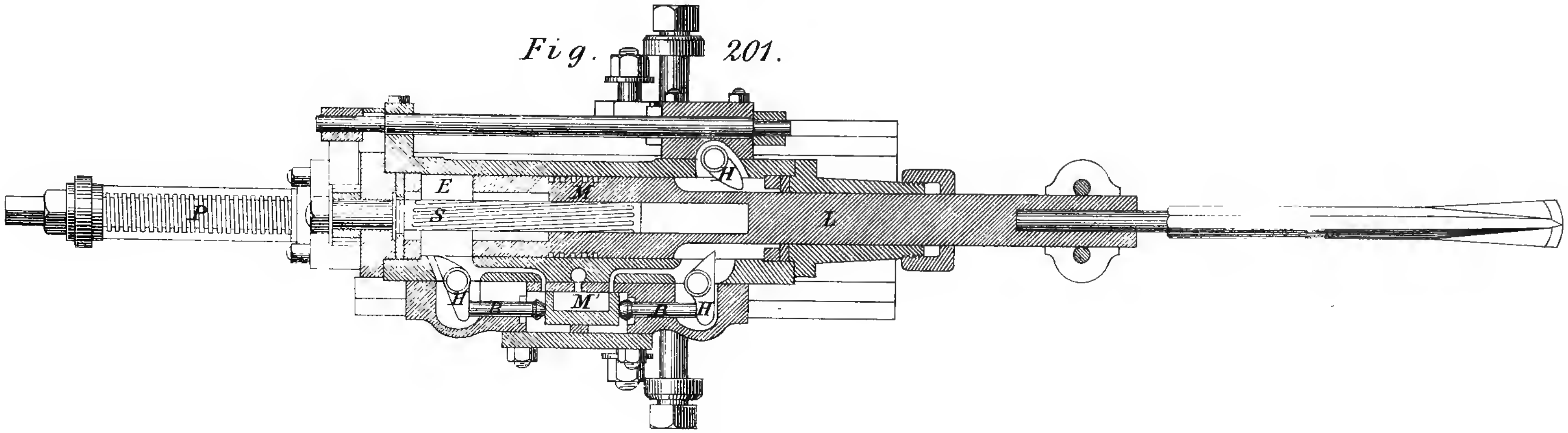
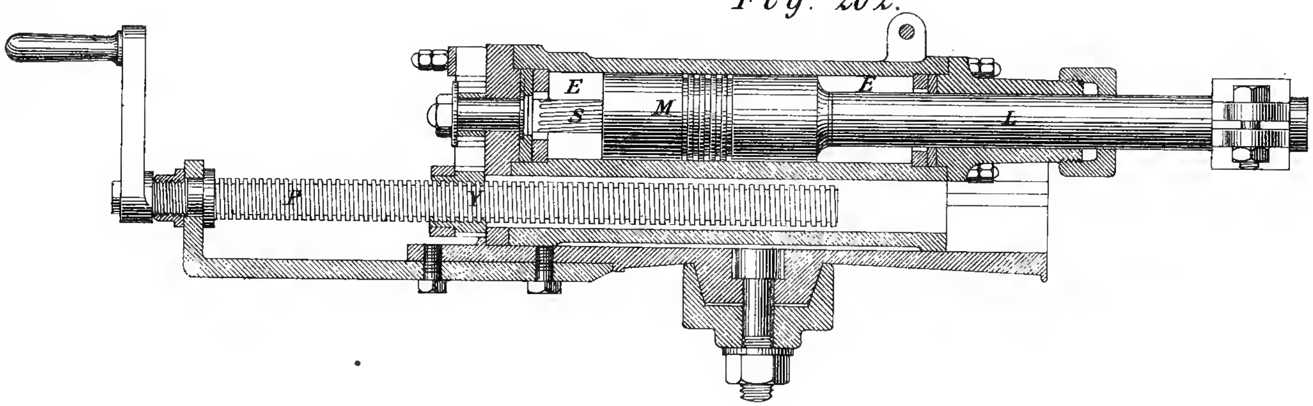


Fig. 202.



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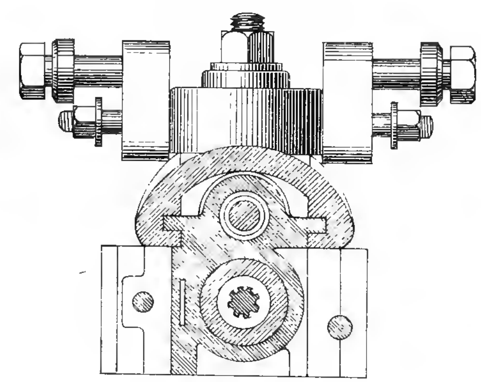

SCALE

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ROCK-BORING MACHINES — SCHRAM.

Fig 204

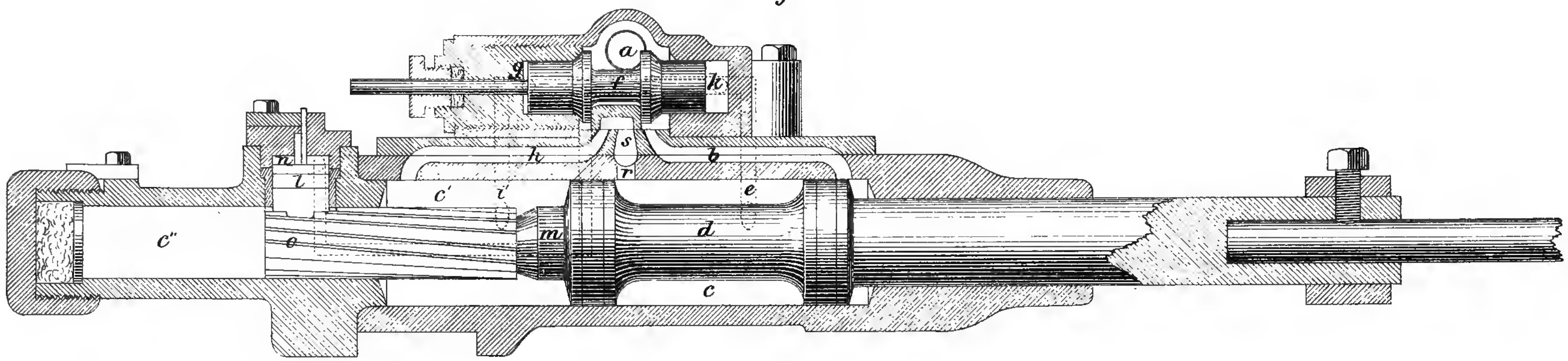
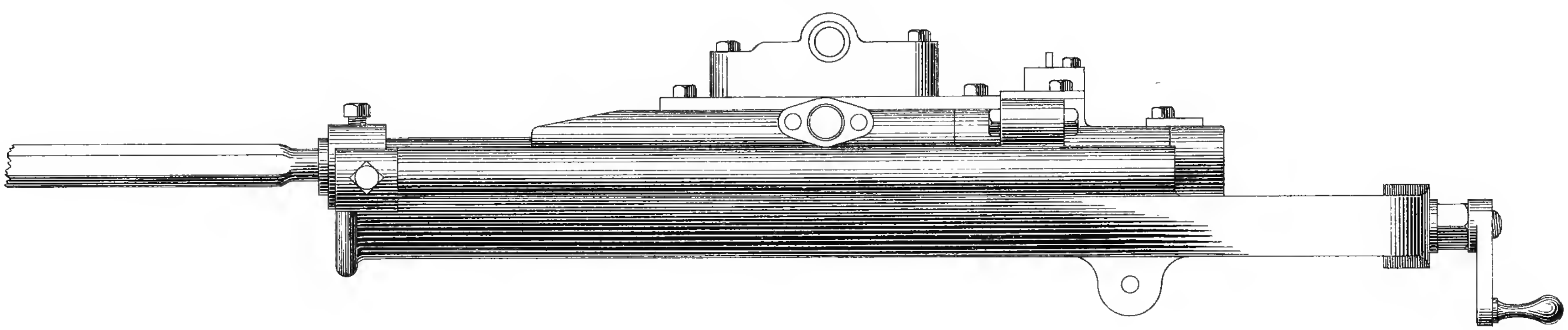
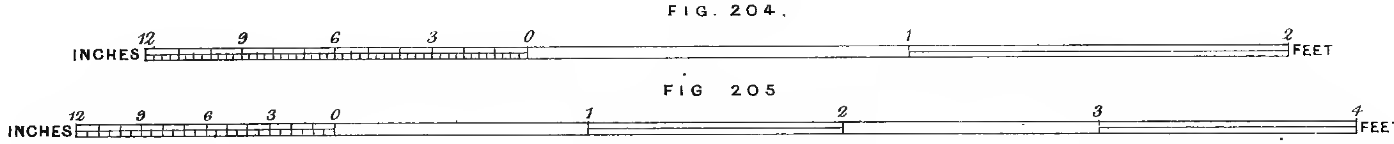


Fig 205





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ROCK-BORING MACHINES — SACHS AND BEAUMONT.

Fig 206

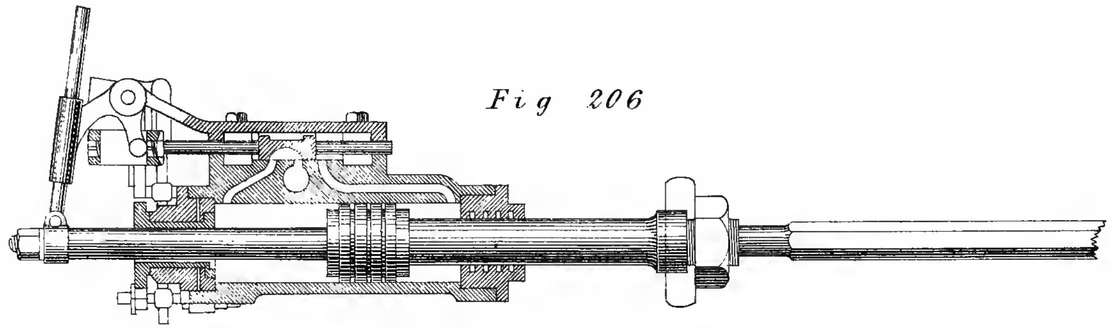
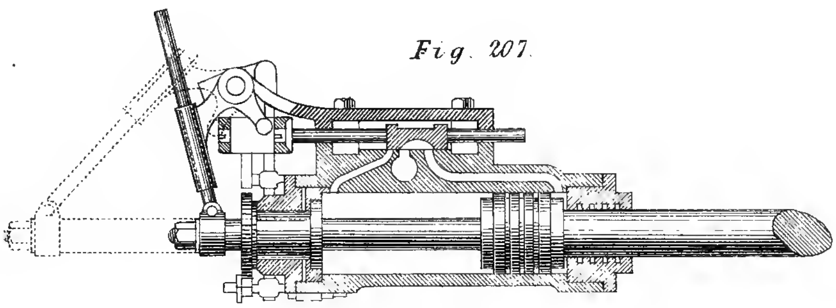


Fig. 207.



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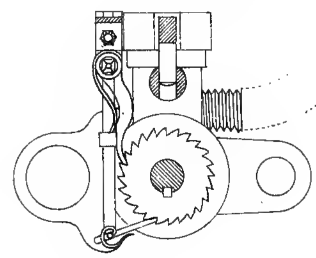


Fig 209

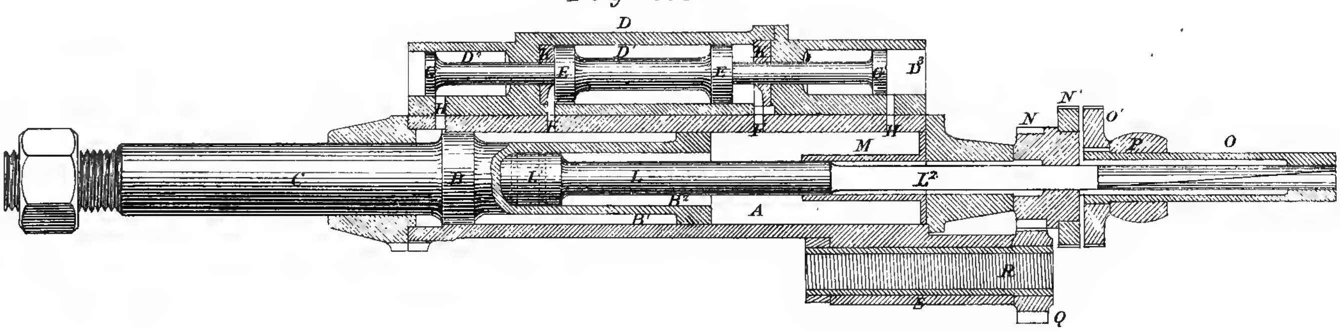
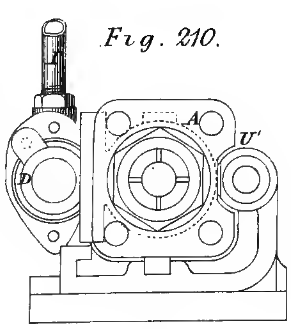


Fig. 210.



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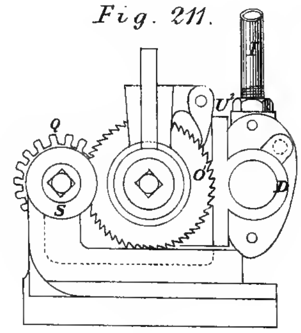

SCALE.

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ROCK-BORING MACHINES — DARLINGTON.

Fig. 212

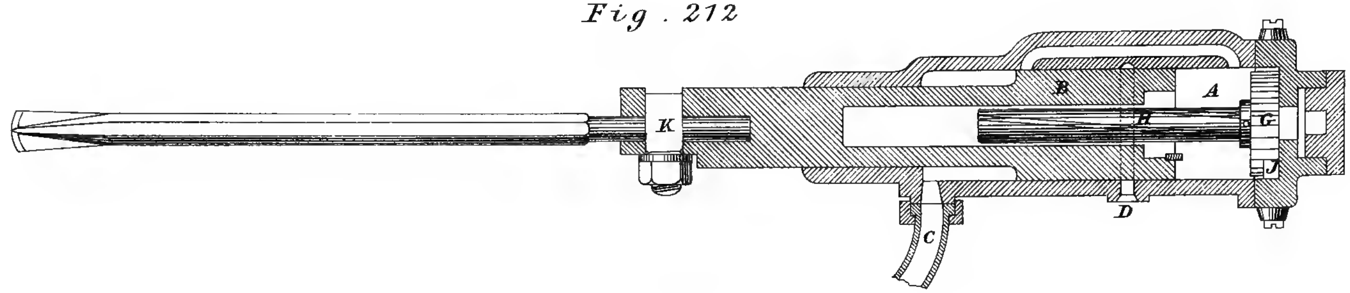


Fig. 213

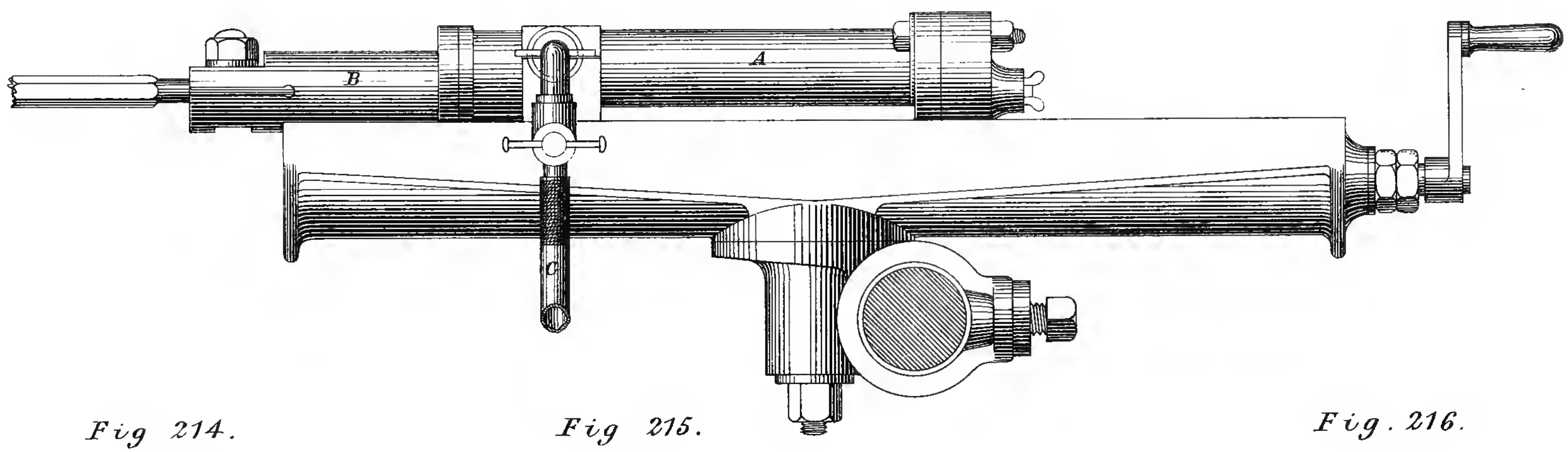


Fig 214.

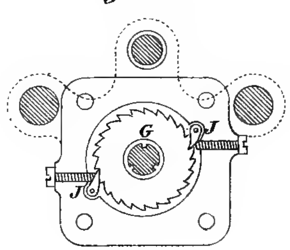


Fig 215.

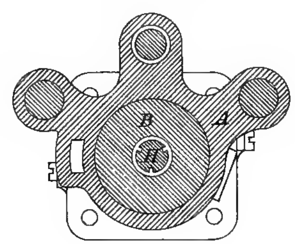


Fig. 217

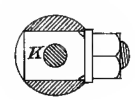
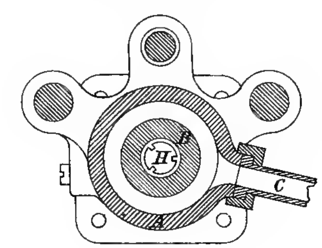
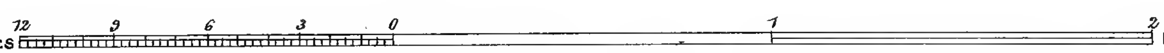


Fig. 216.



S C A L E.



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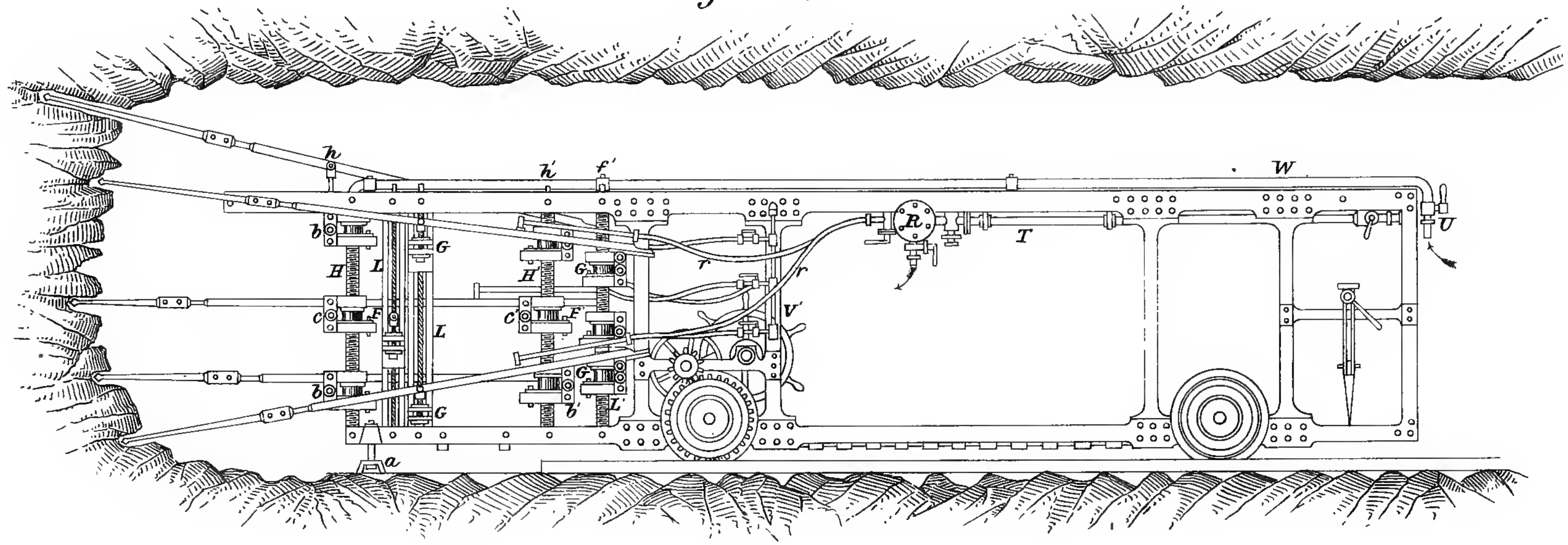
ROCK-BORING MACHINES — Supports.

Fig. 218



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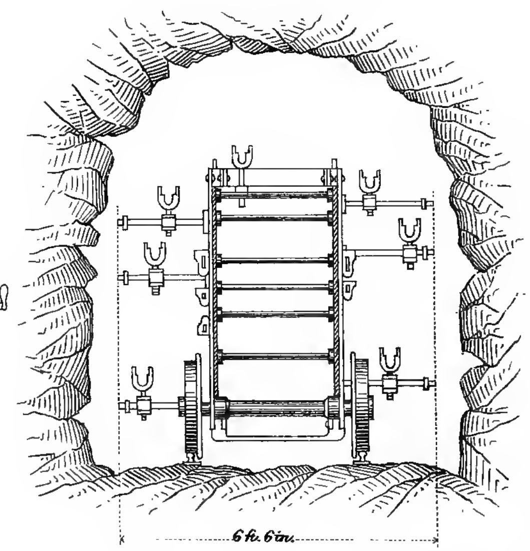

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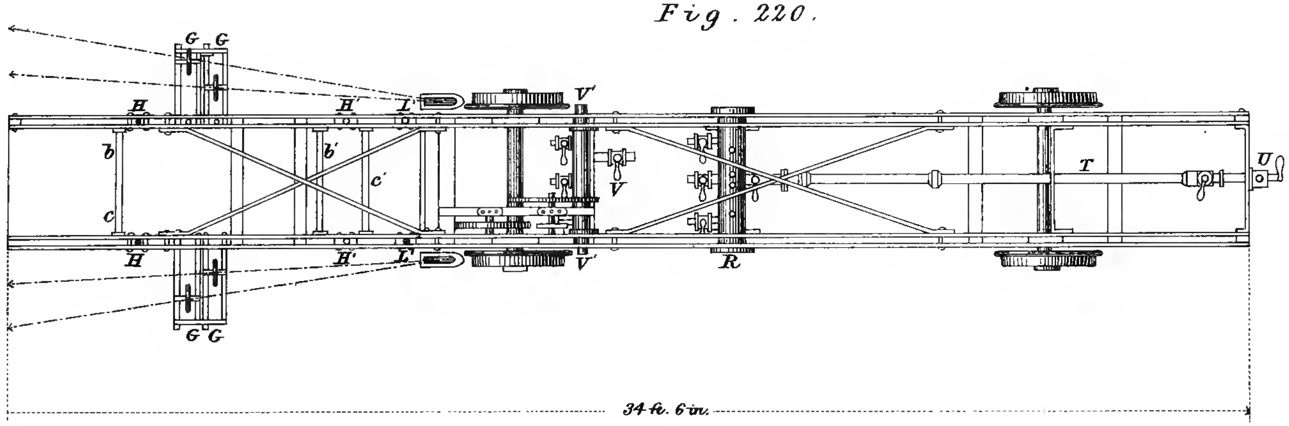

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ROCK-BORING MACHINES — Supports.

Fig. 221.

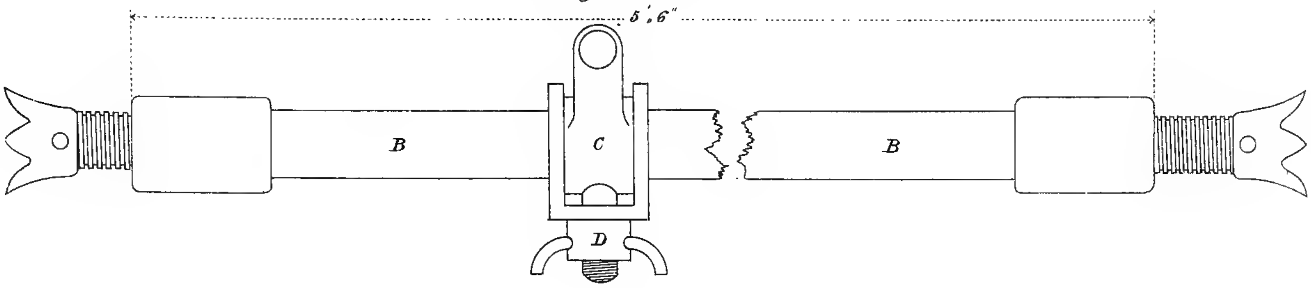


Fig. 222

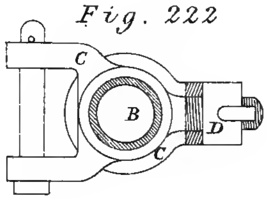


Fig 223

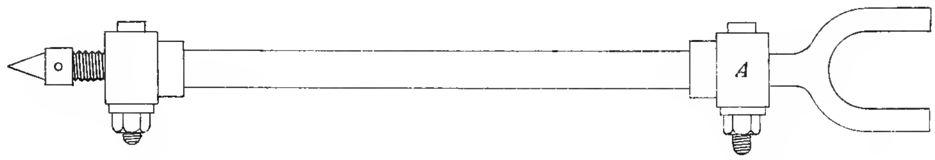
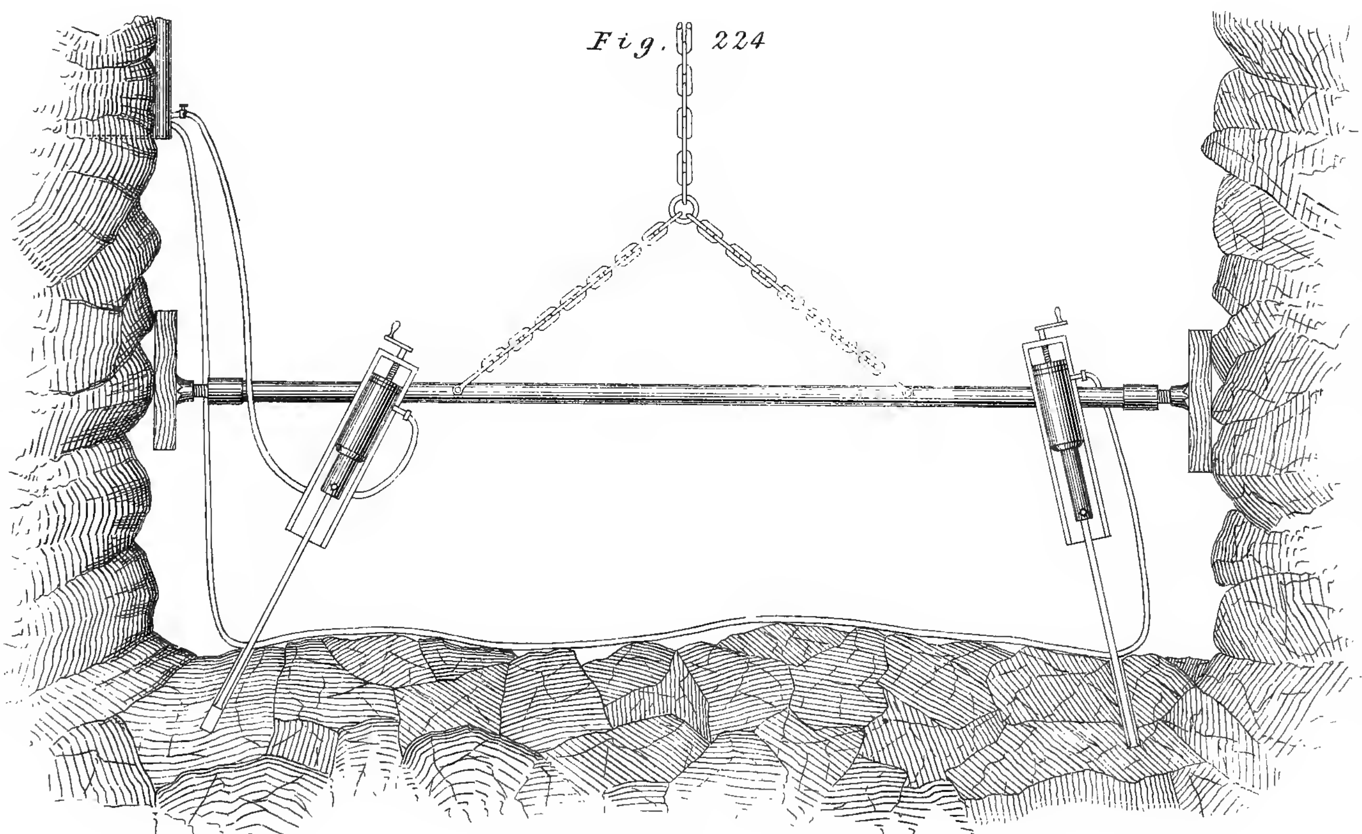


Fig. 224



S C A L E S.

FIGS. 221-223.

INCHES 12 9 6 3 0 1 2 FEET.

FIG. 224.

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 FEET.

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ROCK-BORING MACHINES — Supports.

Fig. 225.

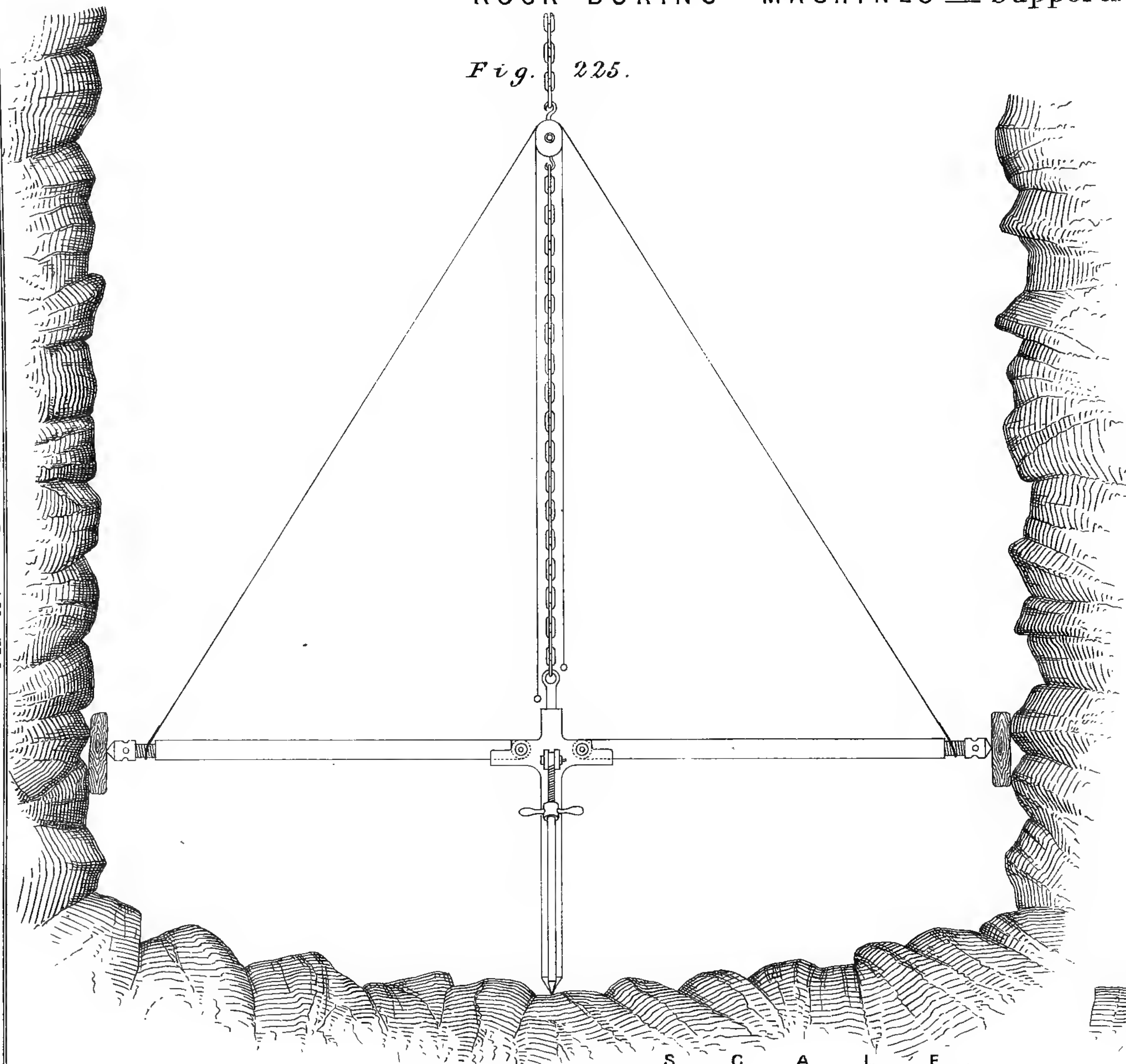


Fig.. 227

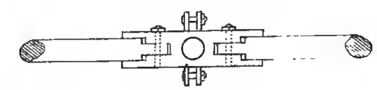
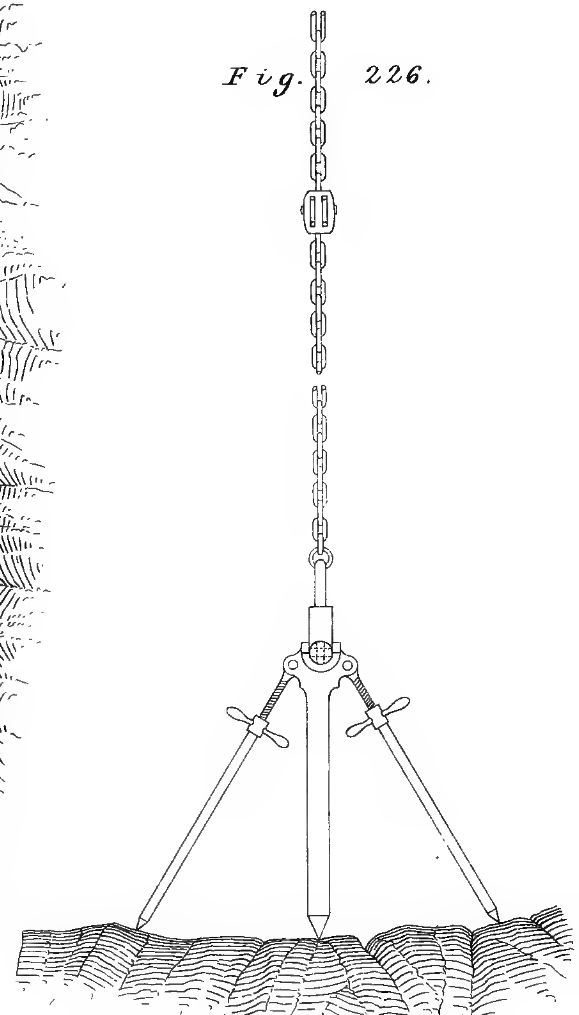


Fig. 226.



SCALE.

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 FEET.

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ROCK-BORING MACHINES — Supports.

Fig. 228

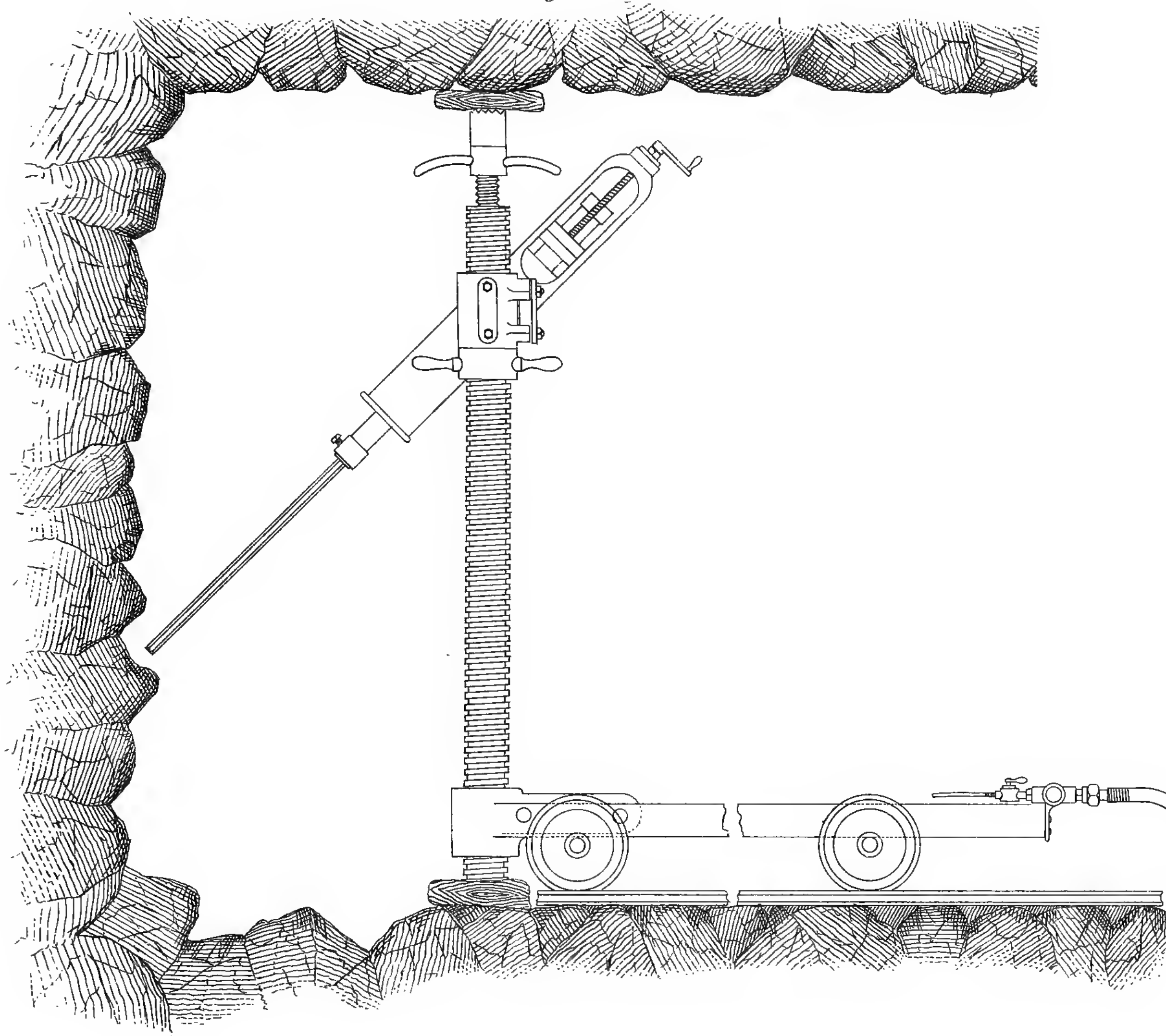
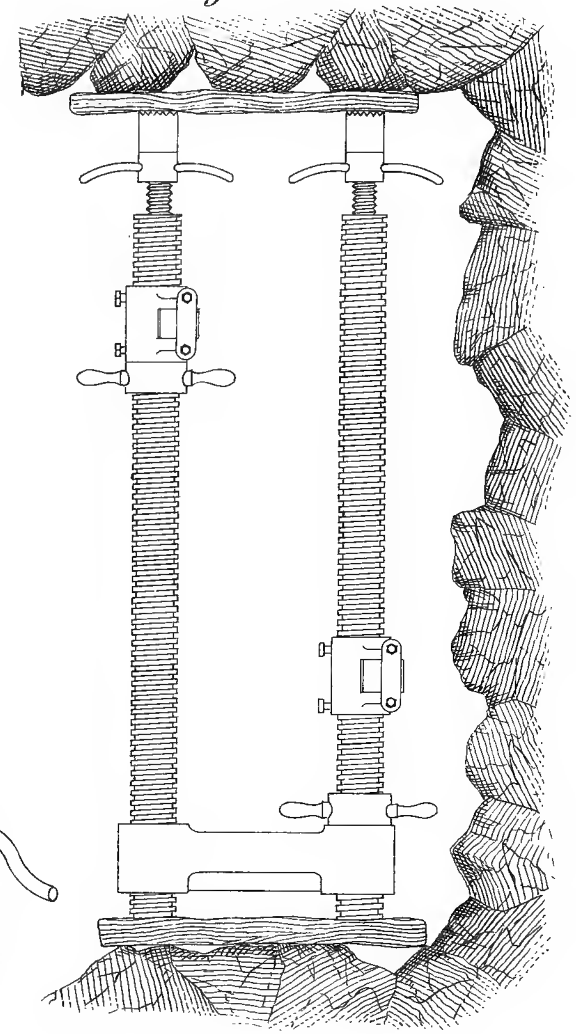


Fig. 229.



SCALE.

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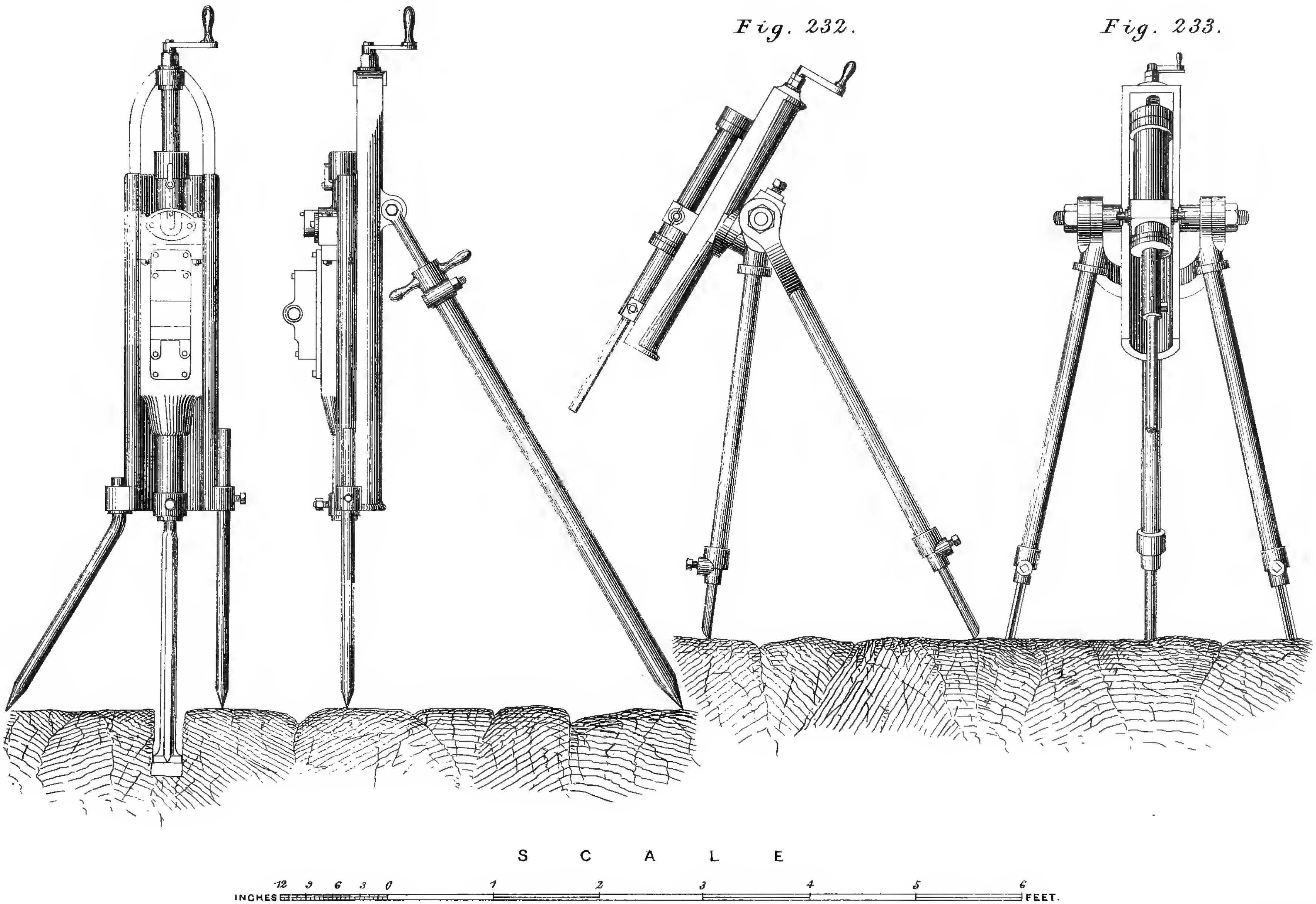
ROCK-BORING MACHINES — Supports.

Fig. 230. Fig. 231. Fig. 232. Fig. 233.



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AIR-COMPRESSORS — SOMMEILLER.

Fig 234.

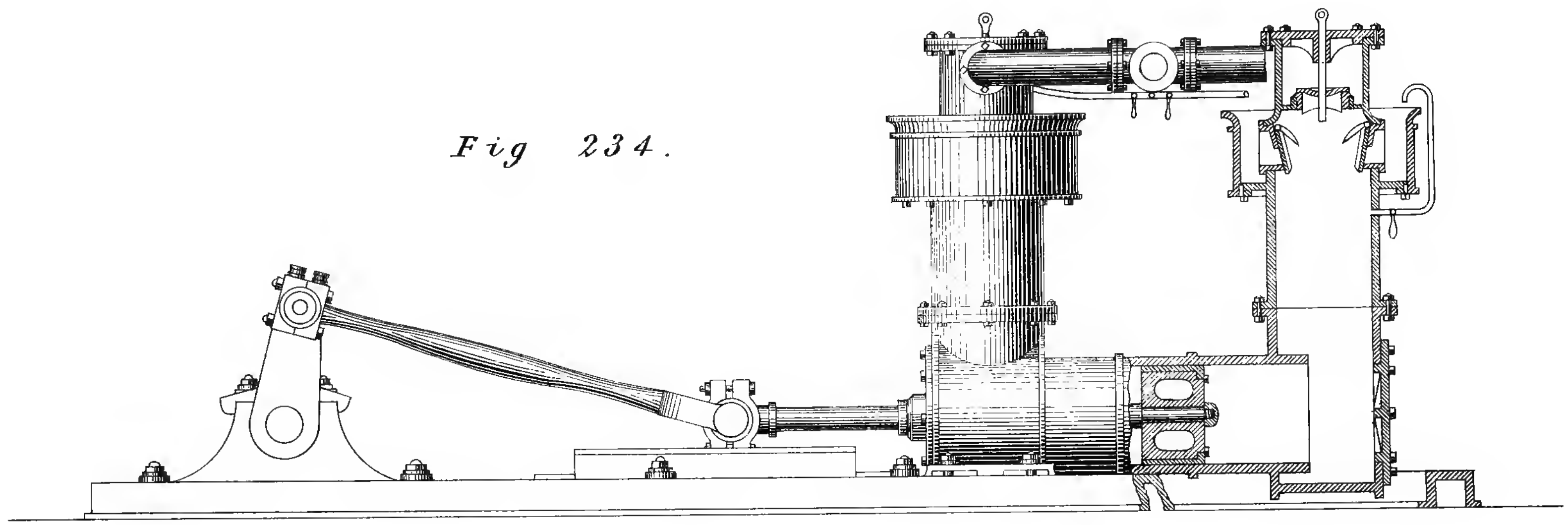
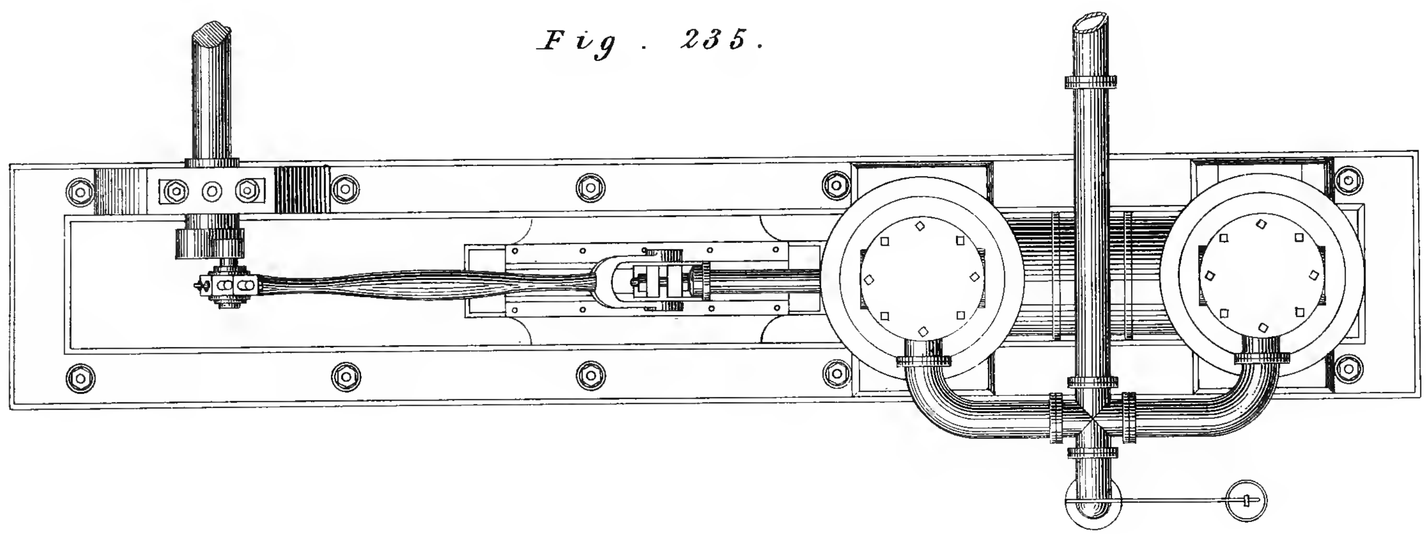


Fig. 235.



SCALE.

INCHES 12 9 6 3 0 1 2 3 4 5 10 15 20 FEET.

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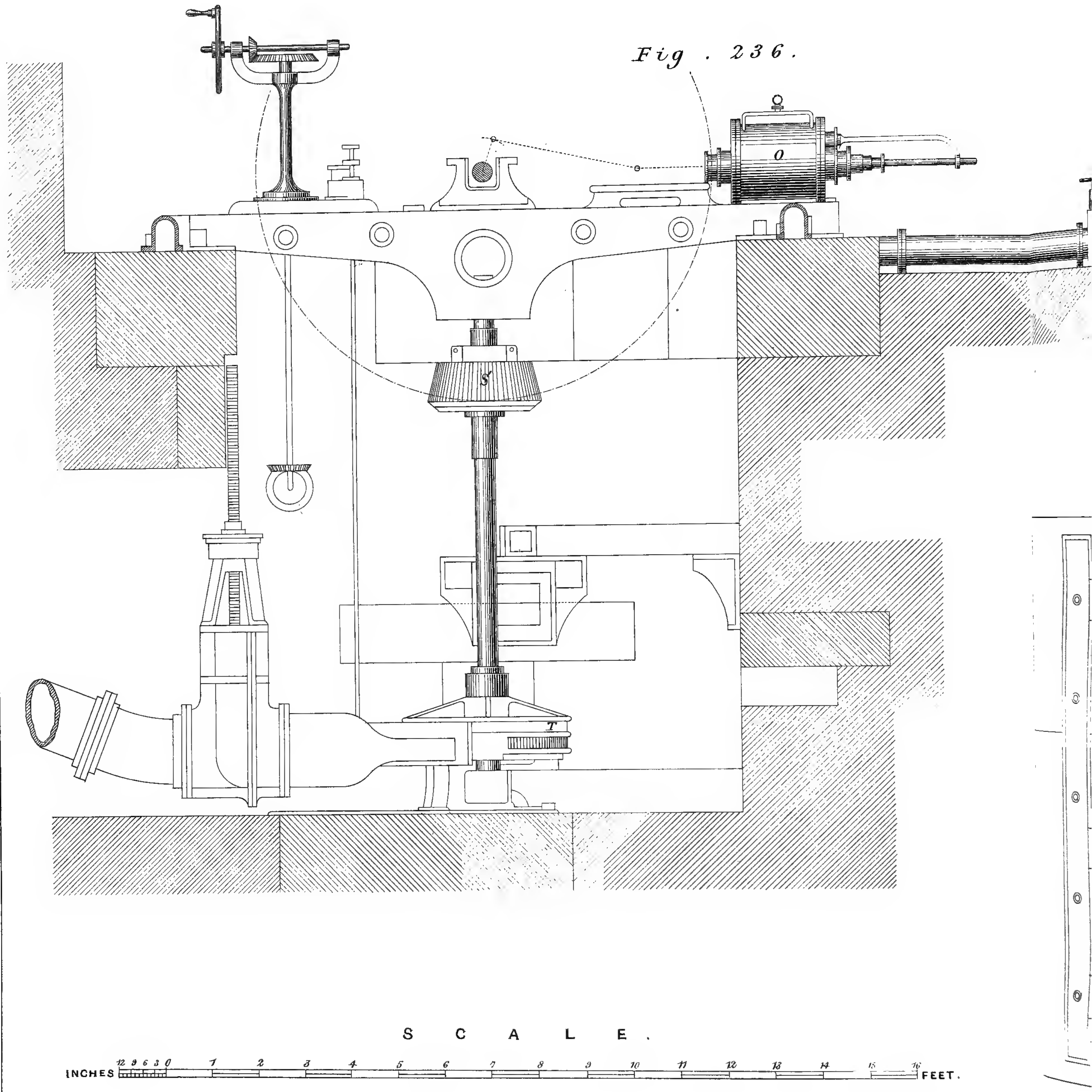
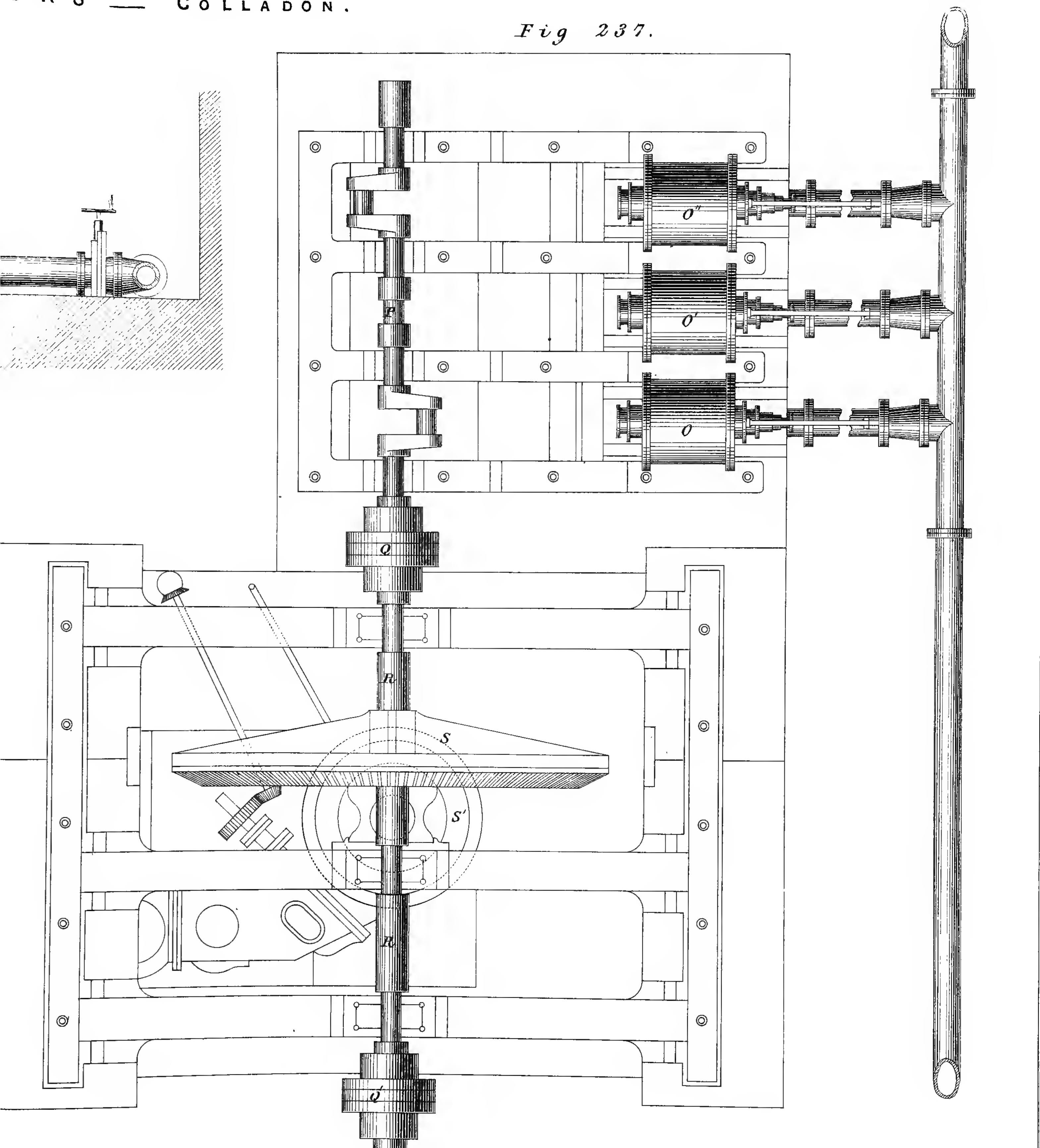
AIR-COMPRESSORS



E & F. N. Spon. London & New

ORS — COLLADON.

Fig 237.



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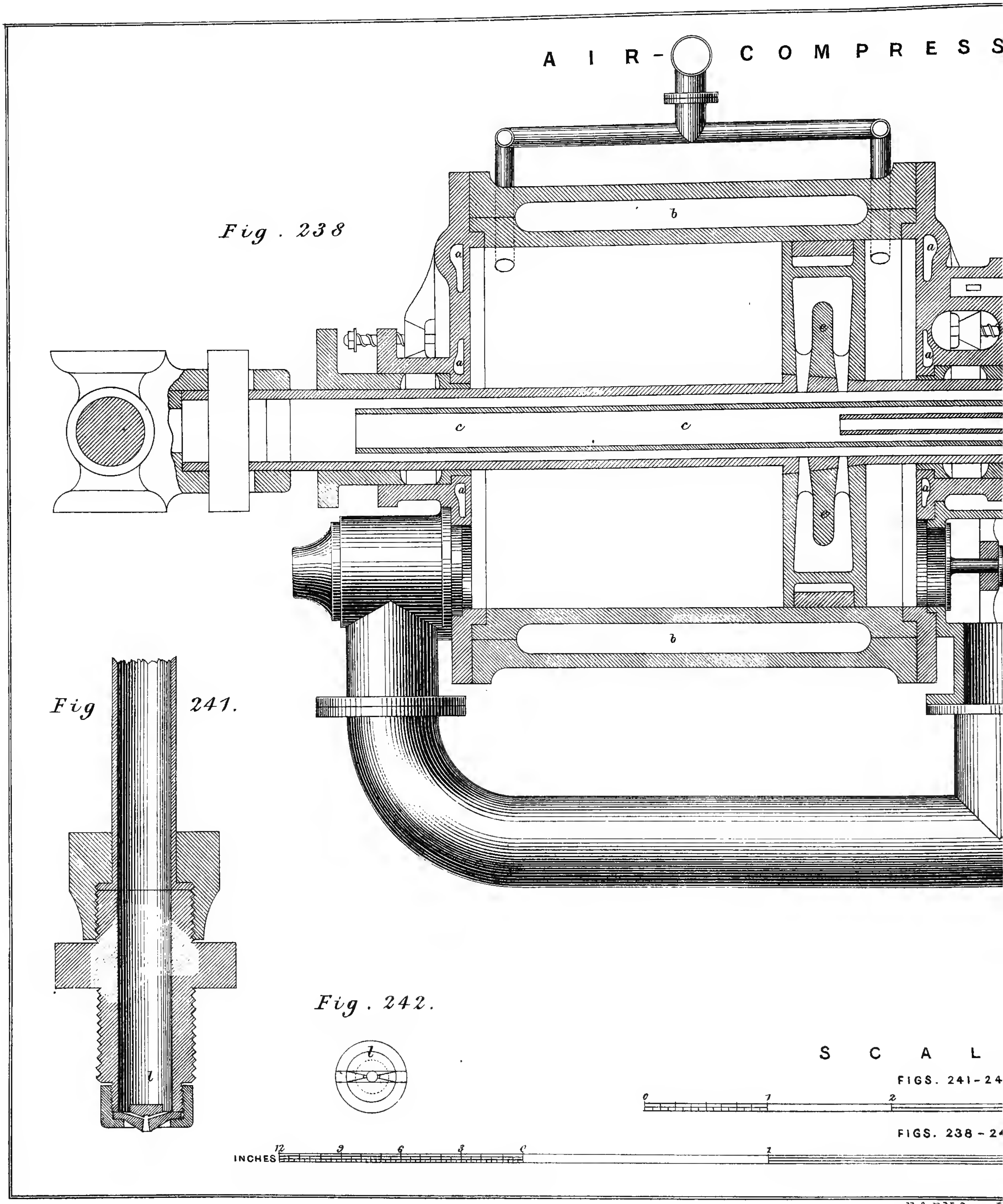
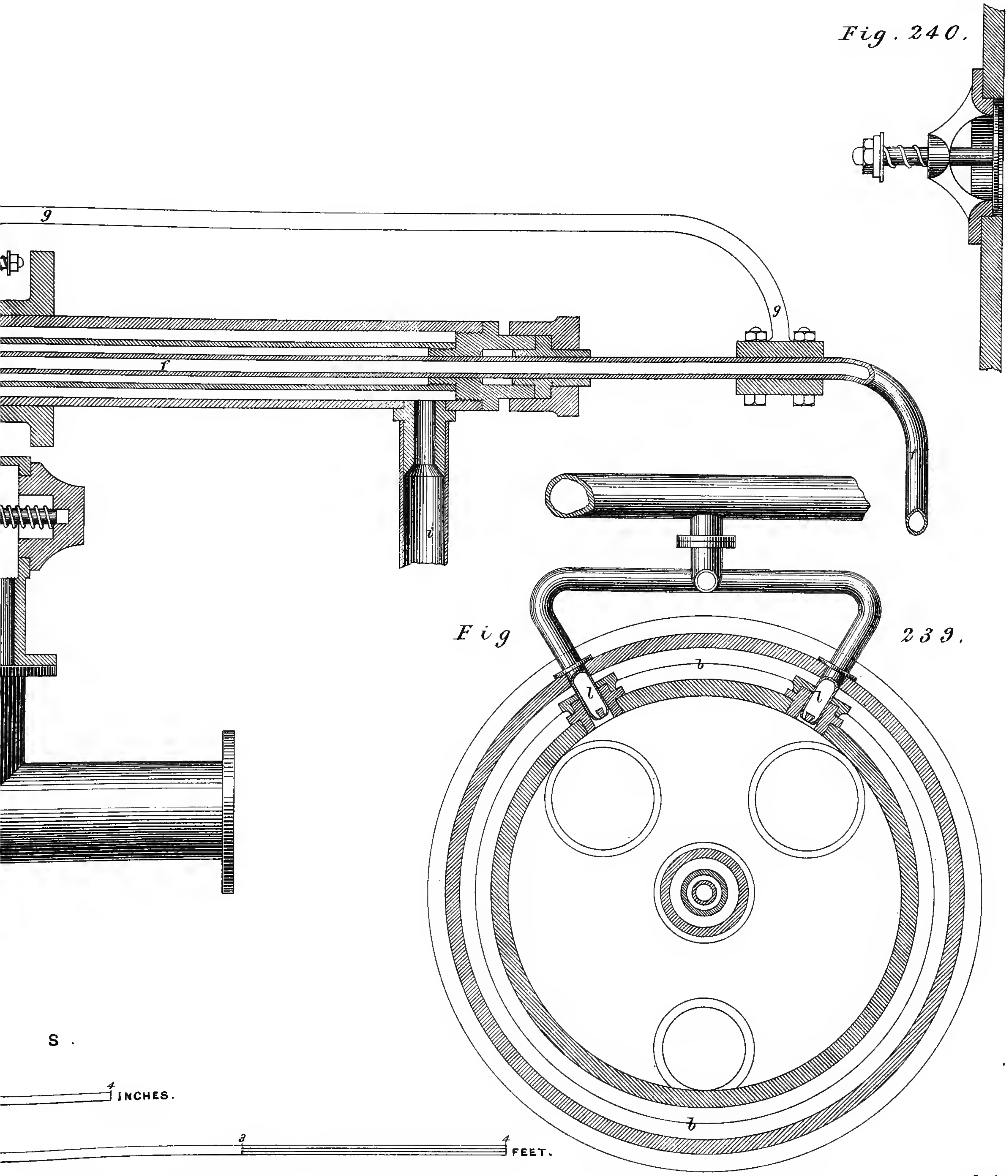
don & New York.


AIR-COMPRESS
Fig. 238
a
b
c
e
Fig 241.
l
Fig. 242.
S C A L
FIGS. 241-24
0
1
2
FIGS. 238-24
INCHES
12
9
6
3
0
1

E. & F.N.Spon. L

ORS — COLLADON — Details.



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& New York.

A I R — C O M P R E

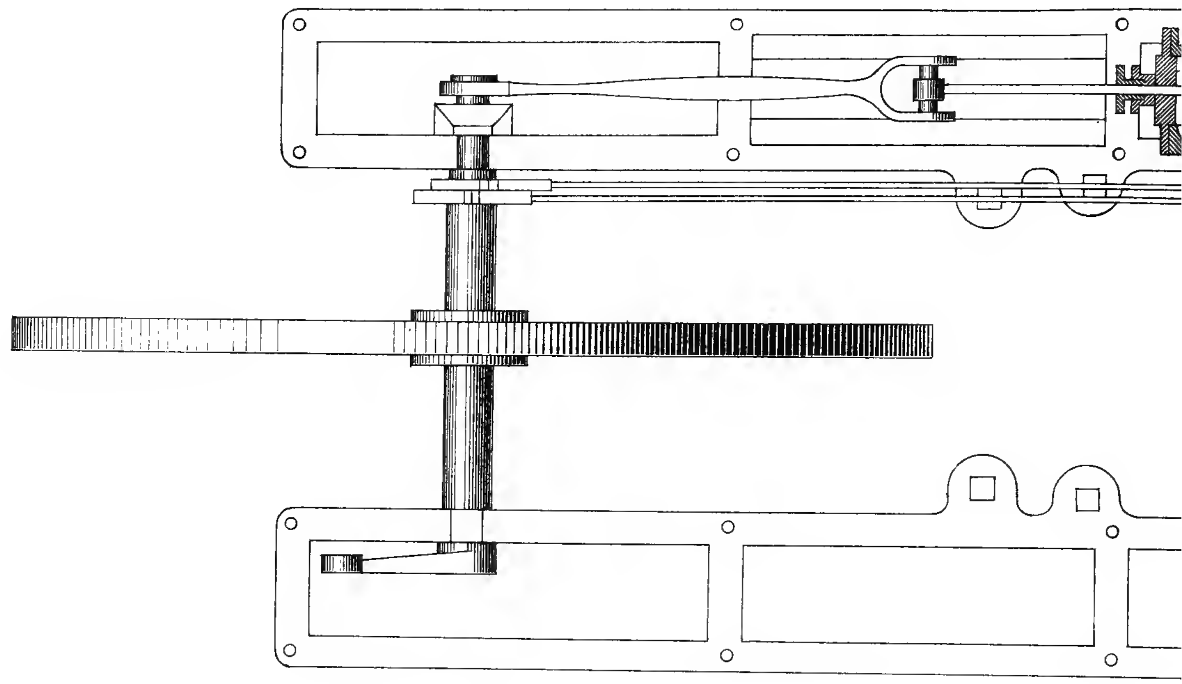
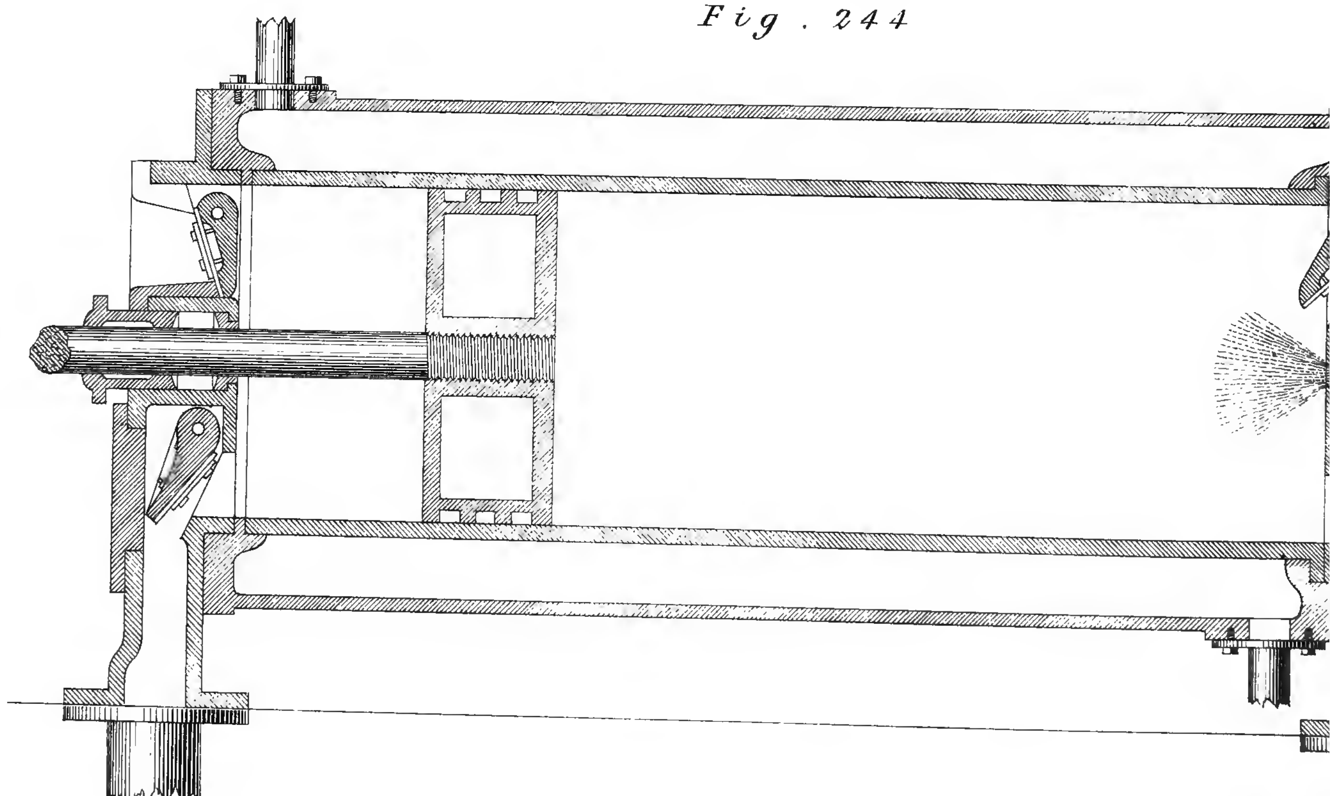
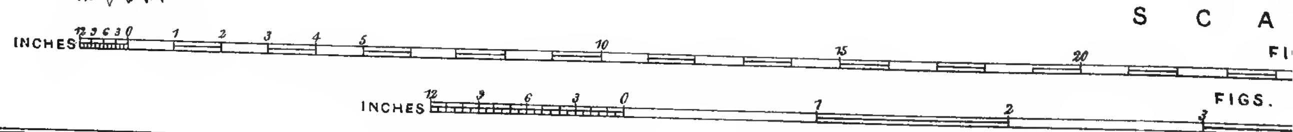


Fig. 244



S C A



E & F.N Spon. Lo

S O R S — B L A N Z Y.

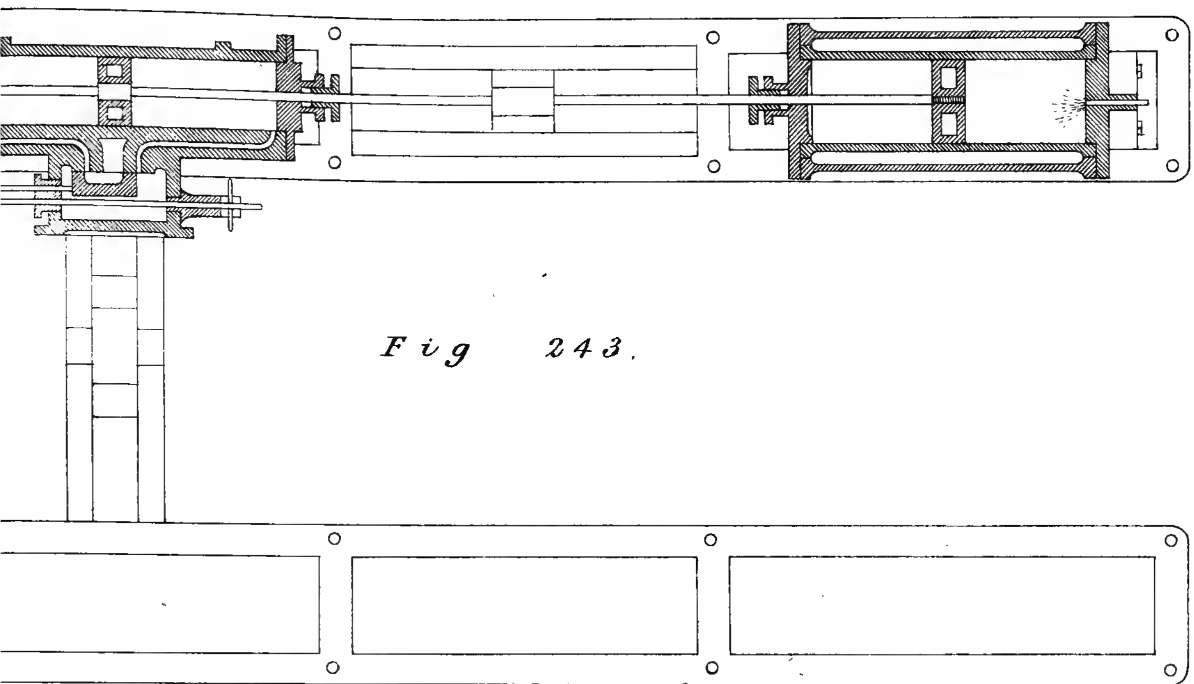
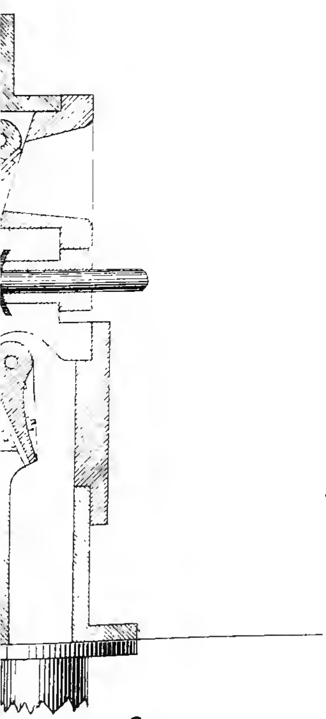
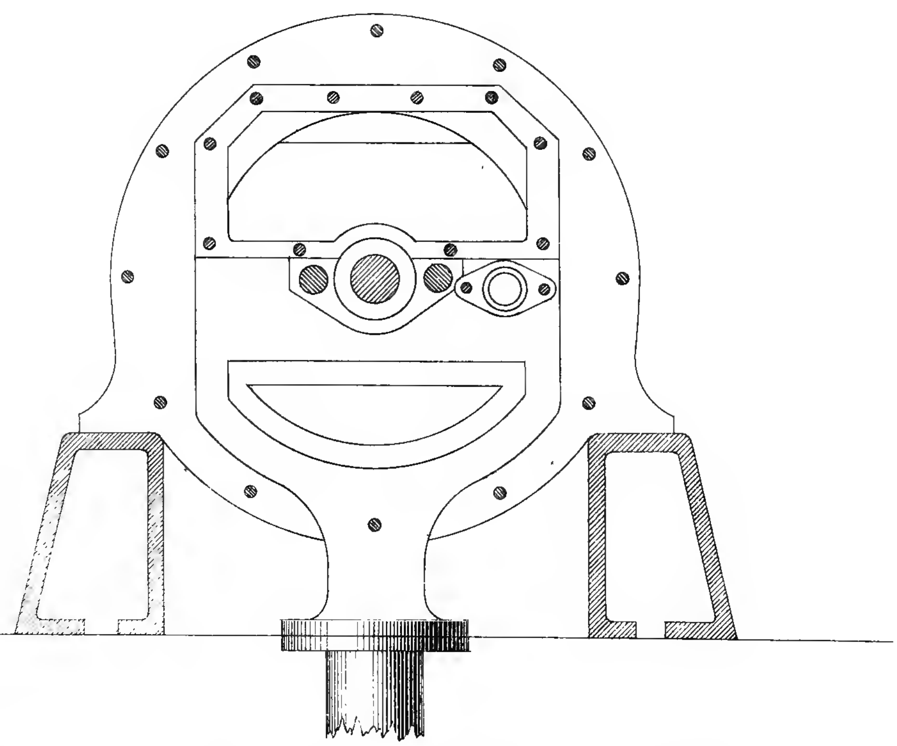


Fig 243.

Fig. 245.





L E S.

243. 30 35 40 45 50 FEET.

4 – 245. 4 5 6 7 8 FEET.

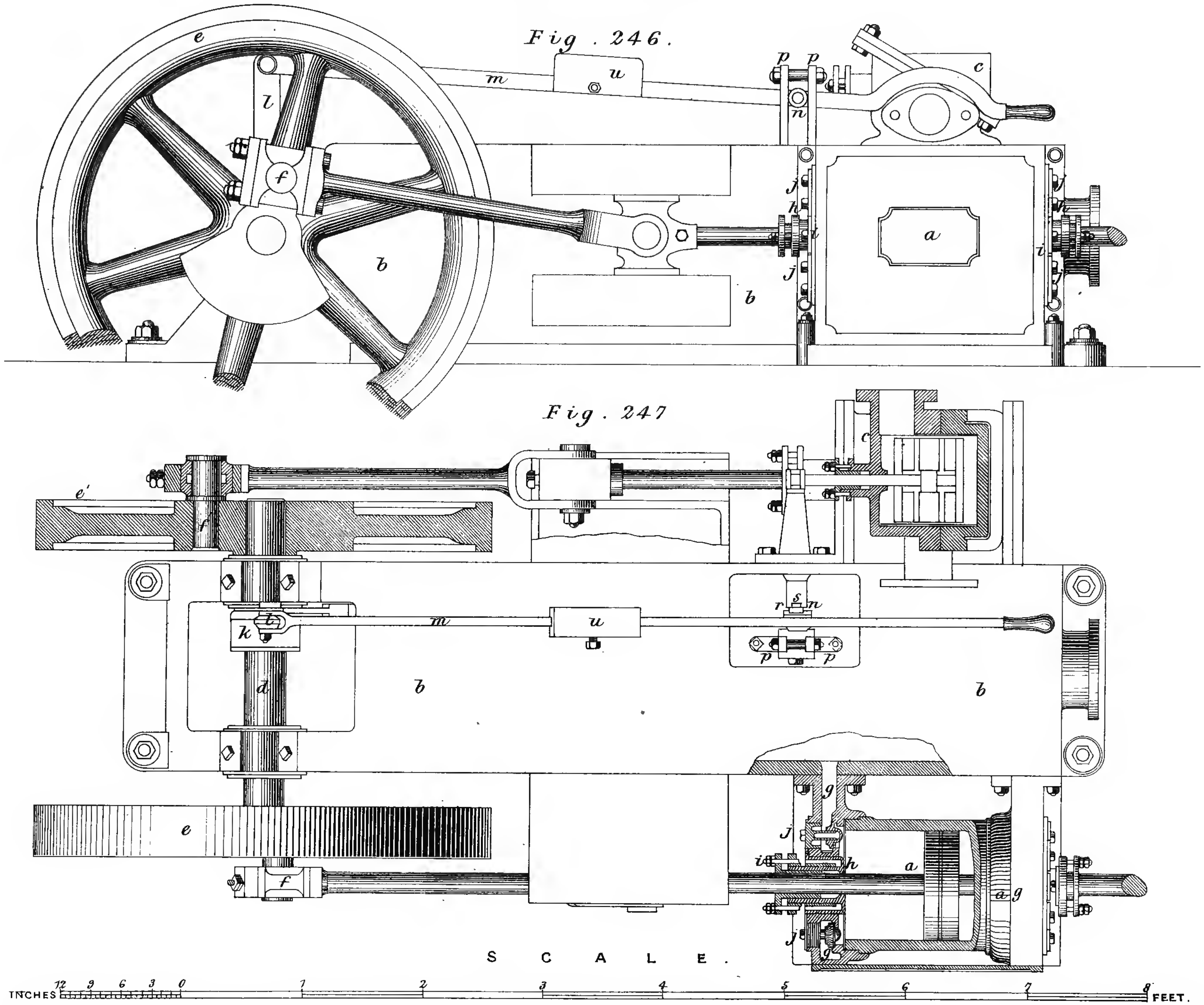
G.G.ANDRÉ.

n & New York.

AIR – COMPRESSORS — STURGEON.

Fig. 246.

Fig. 247



G. G. ANDRÉ.

E & F N Spon London & New York.

AIR-COMPRESSORS,

Fig. 248.

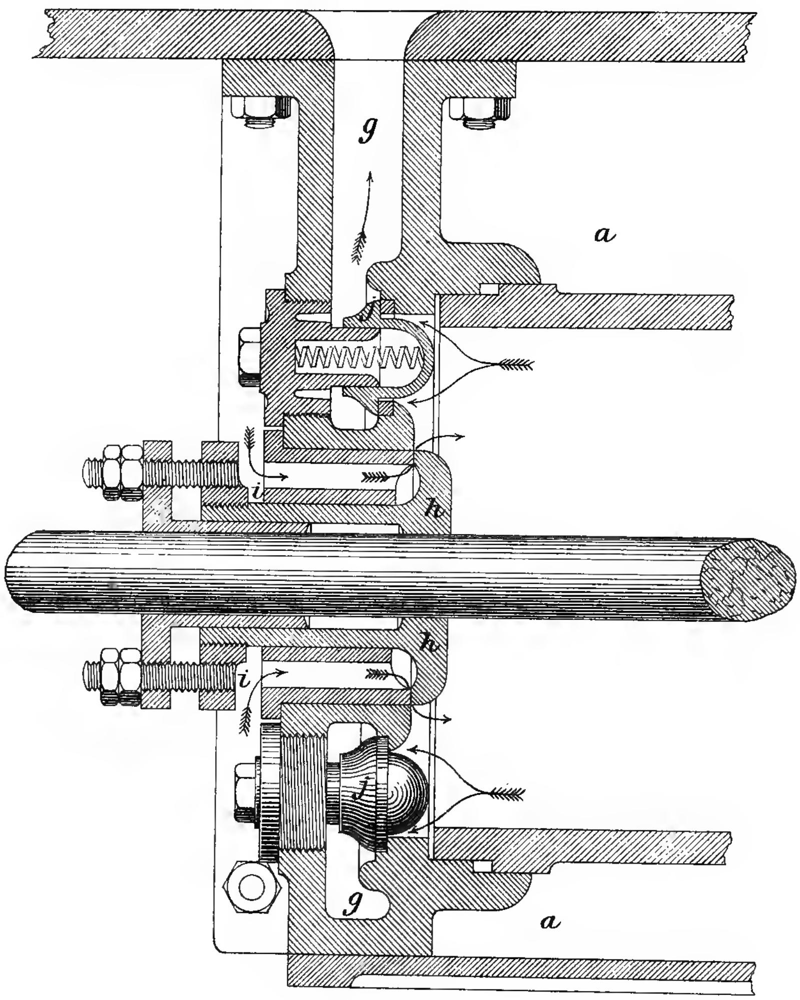


Fig. 250.

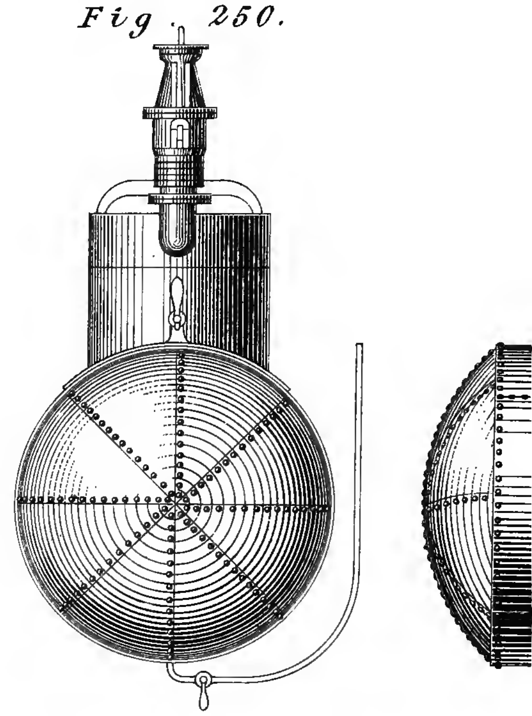


Fig. 251.

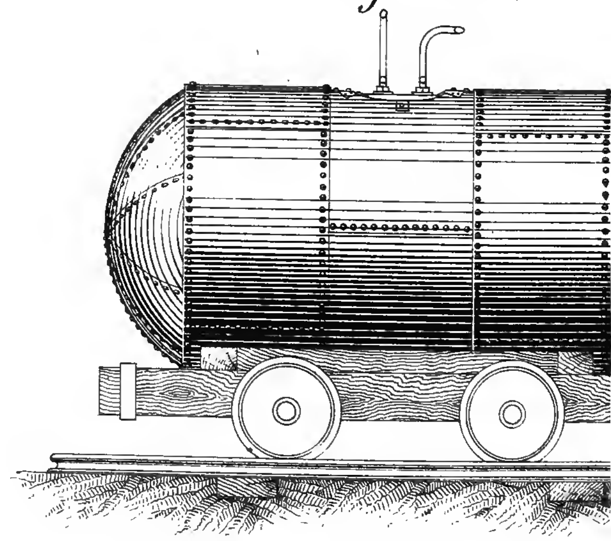
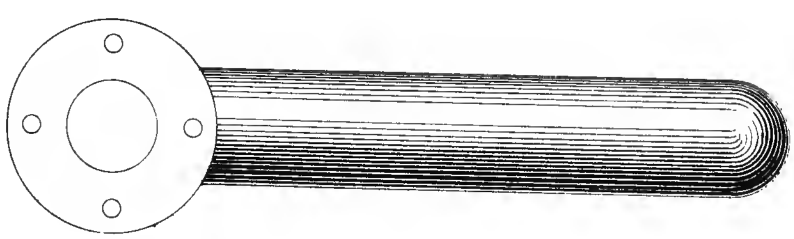


Fig. 254.



S C A

FIG

INCHES 12 9 6 3

FIGS.

INCHES 12 3 6 8 0 1 2 3 4 5 10

FIGS.

INCHES 12 9 6 3 0 1

I R - R E C E I V E R S, E T C.

Fig 249.

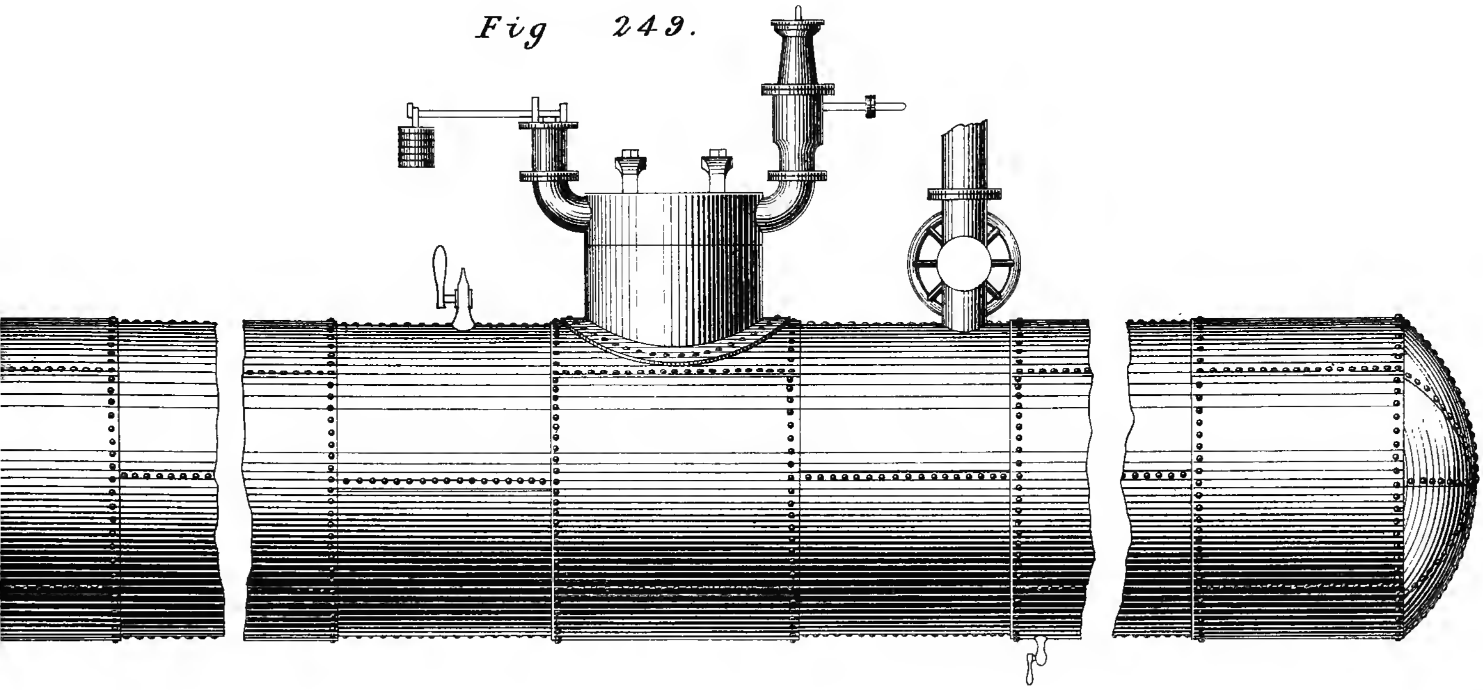


Fig. 252.

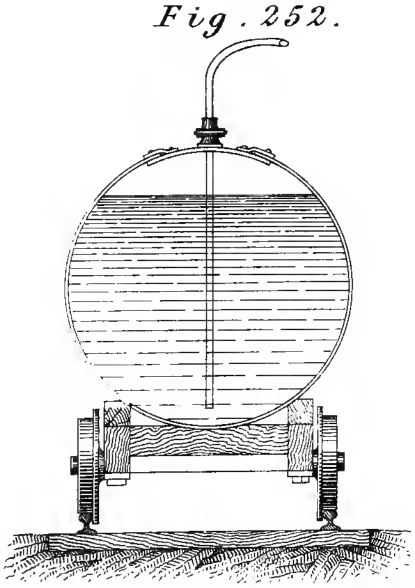
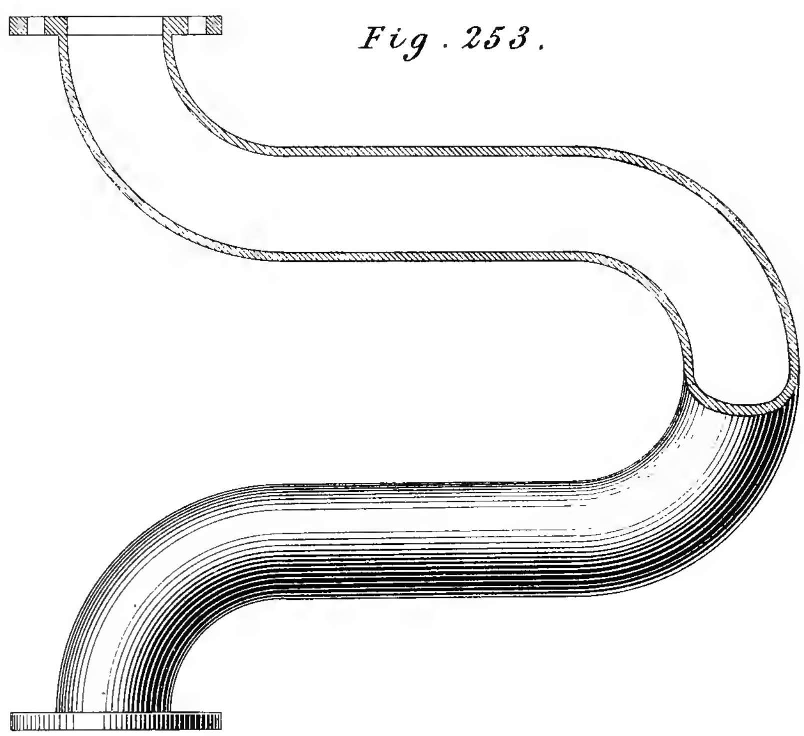


Fig. 253.



L E S .

48 .

1 FOOT.

-252 .

15 20 24 FEET.

- 254

2 3 4 FEET

G.G.ANDRÉ.

& New York.

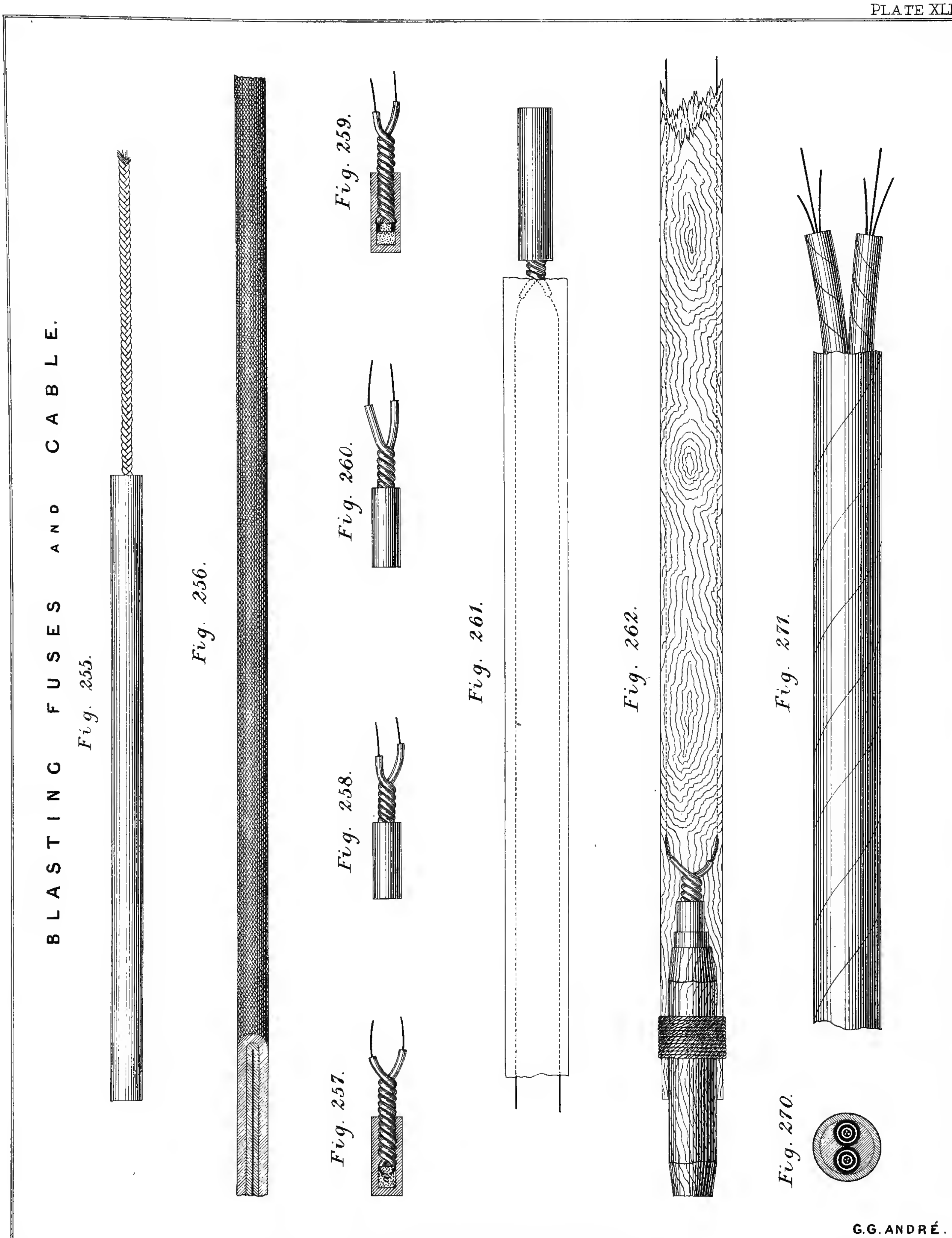


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Fig. 263.

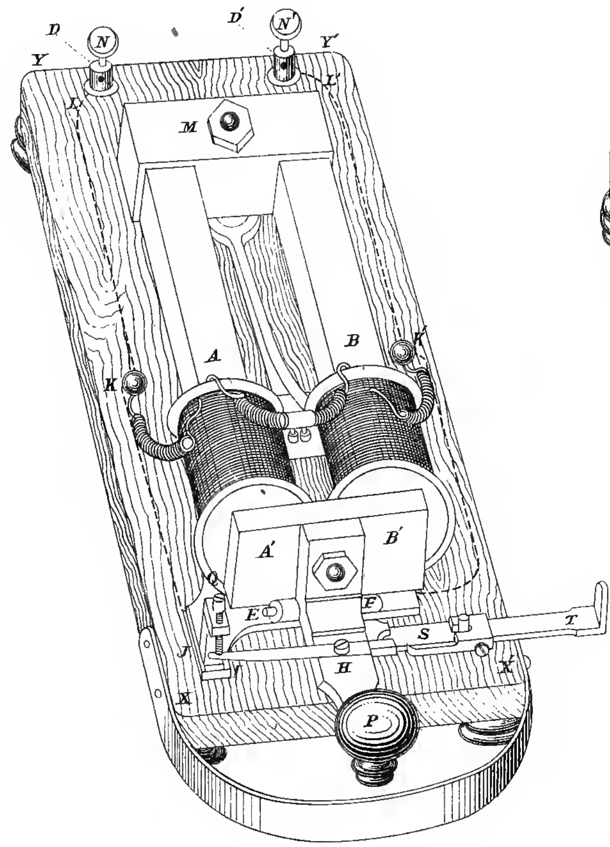
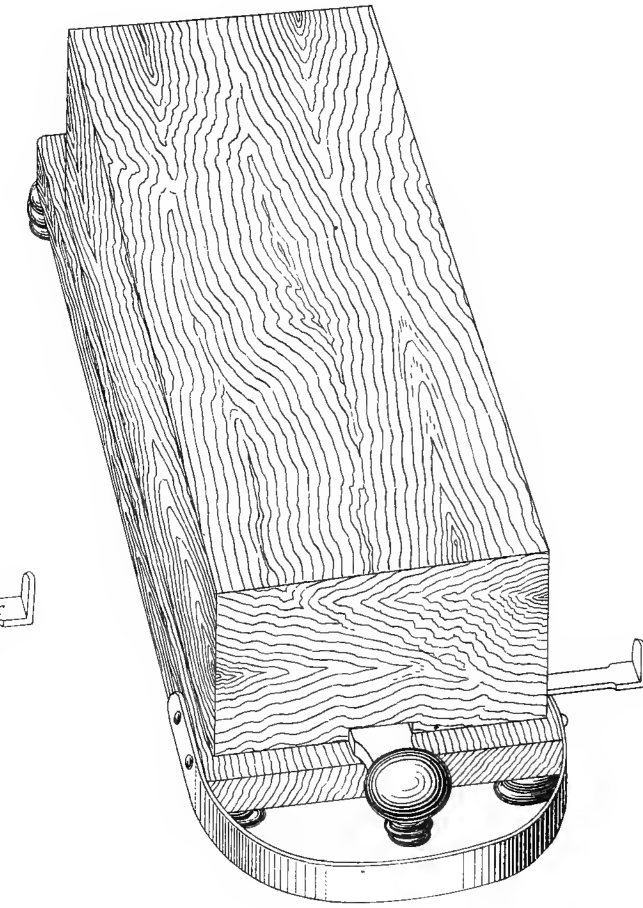


Fig. 264.



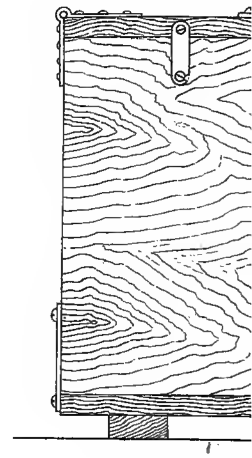


Fig. 265.

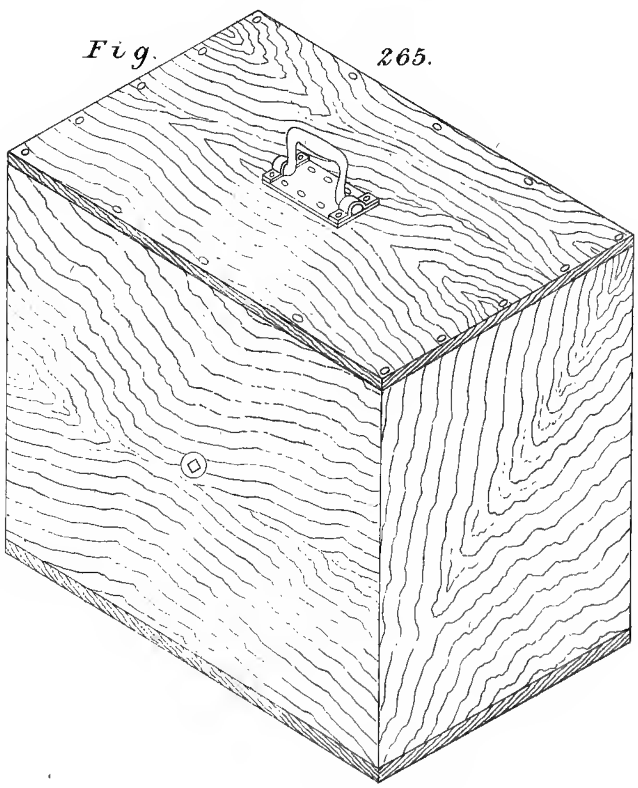
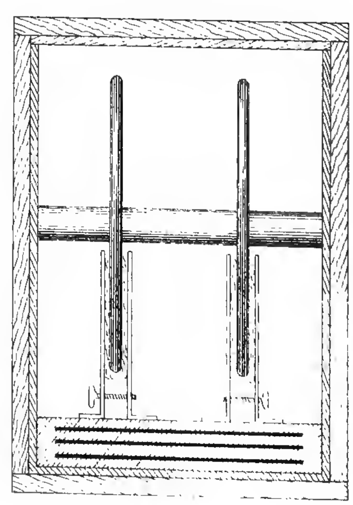


Fig. 266.



INCHES

MACHINES AND CABLE BOX.

Fig. 267.

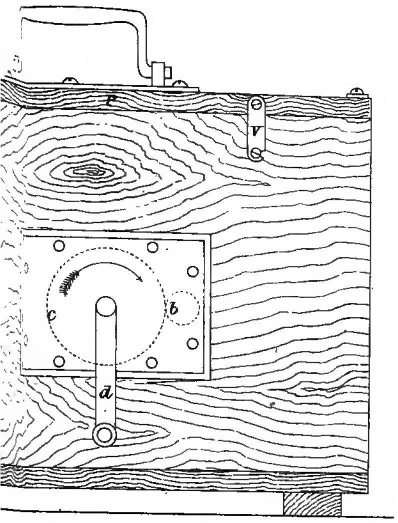


Fig. 268.

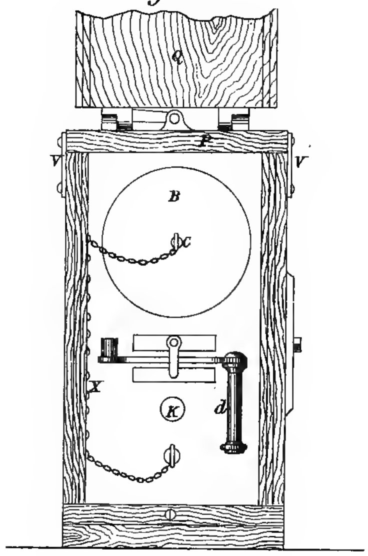


Fig. 269.

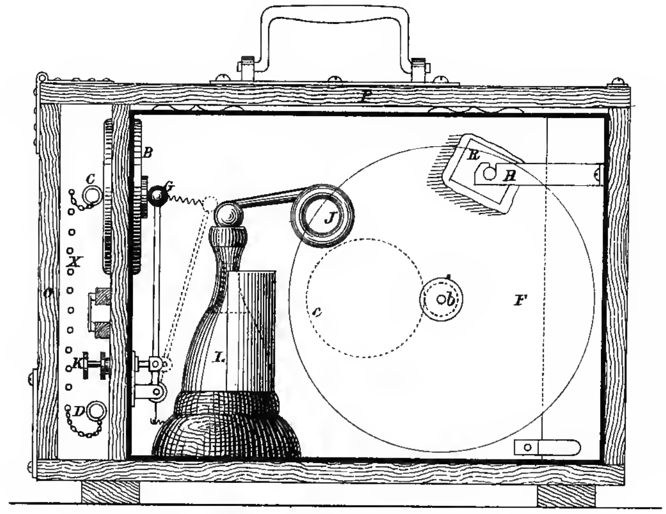


Fig. 272.

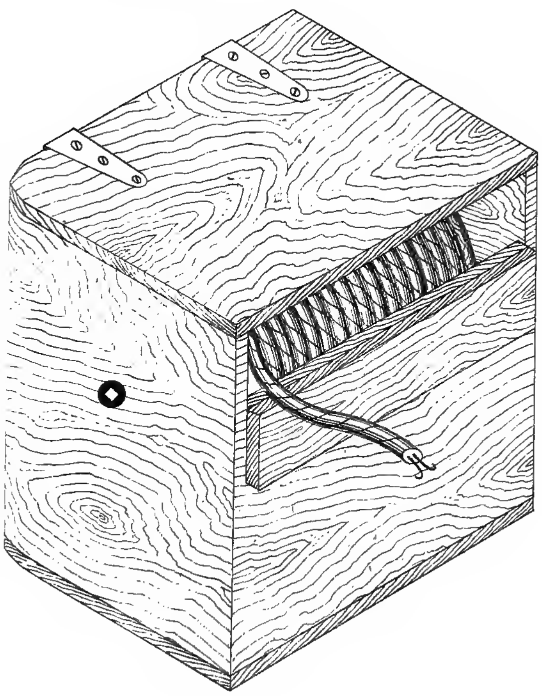
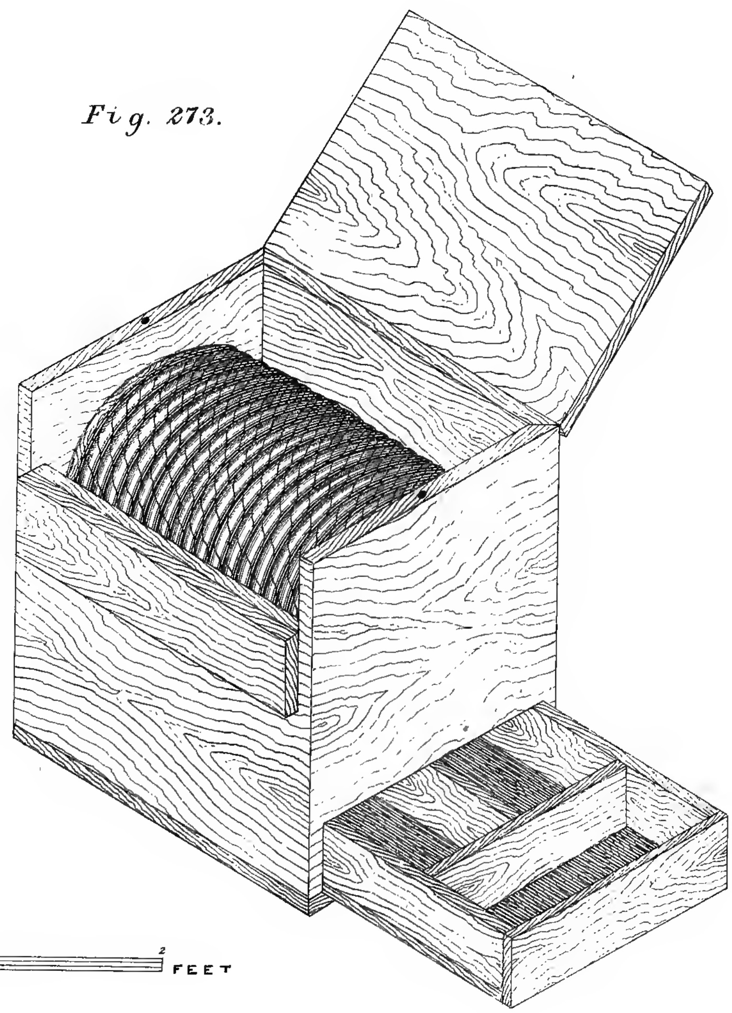


Fig. 273.



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FIGS 266 269.

3 0 1 2 FEET

London & New York.

G.G. ANDRÉ

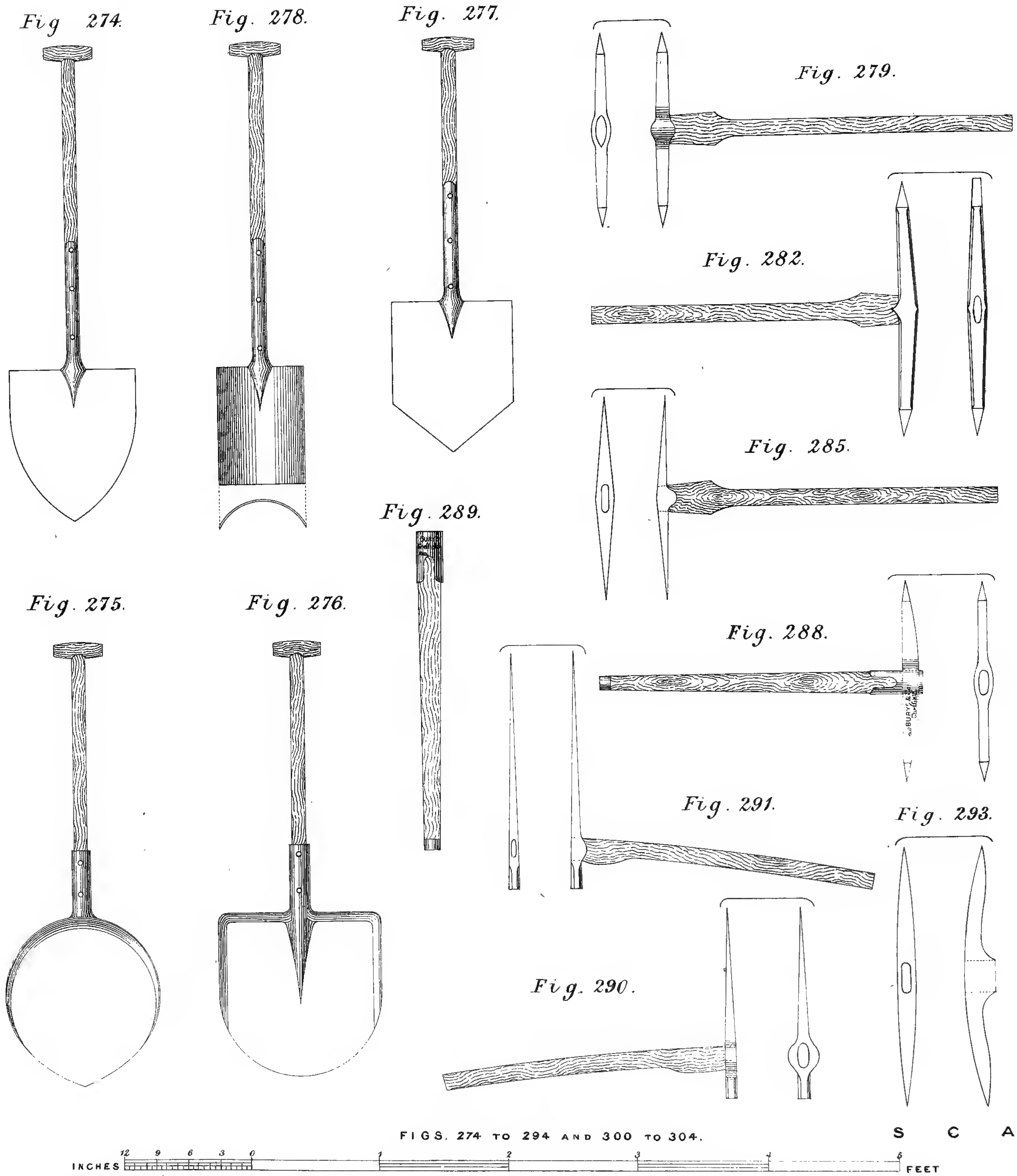
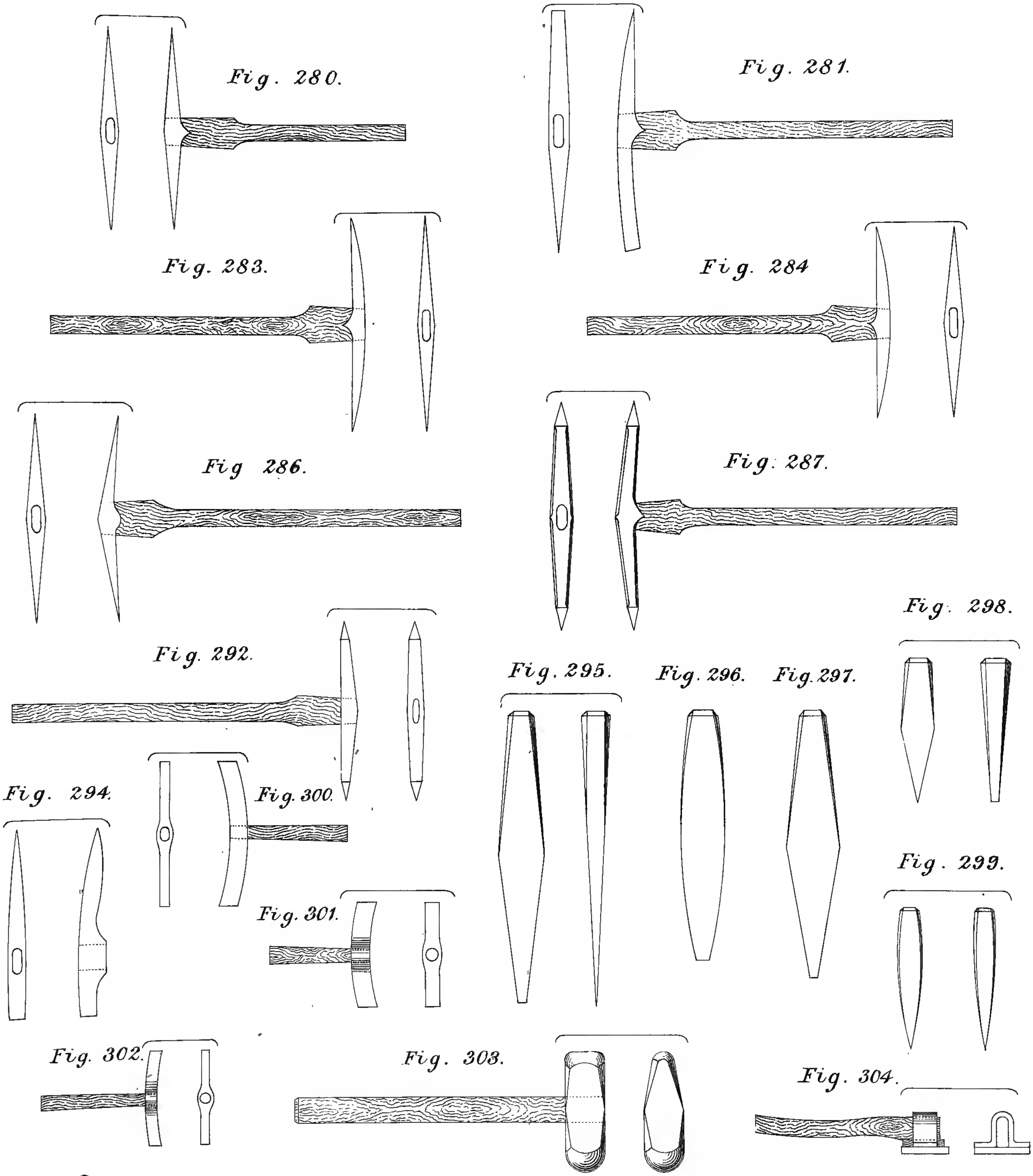


Fig 274.
Fig. 278.
Fig. 277.
Fig. 279.
Fig. 282.
Fig. 285.
Fig. 289.
Fig. 275.
Fig. 276.
Fig. 288.
Fig. 291.
Fig. 293.
Fig. 290.
FIGS. 274 TO 294 AND 300 TO 304.
S C A
INCHES 12 9 6 3 0 1 2 3 4 5 FEET

E & F.N.Spon

S, WEDGES, HAMMERS, ETC.



L E S.

FIGS. 295 TO 299.

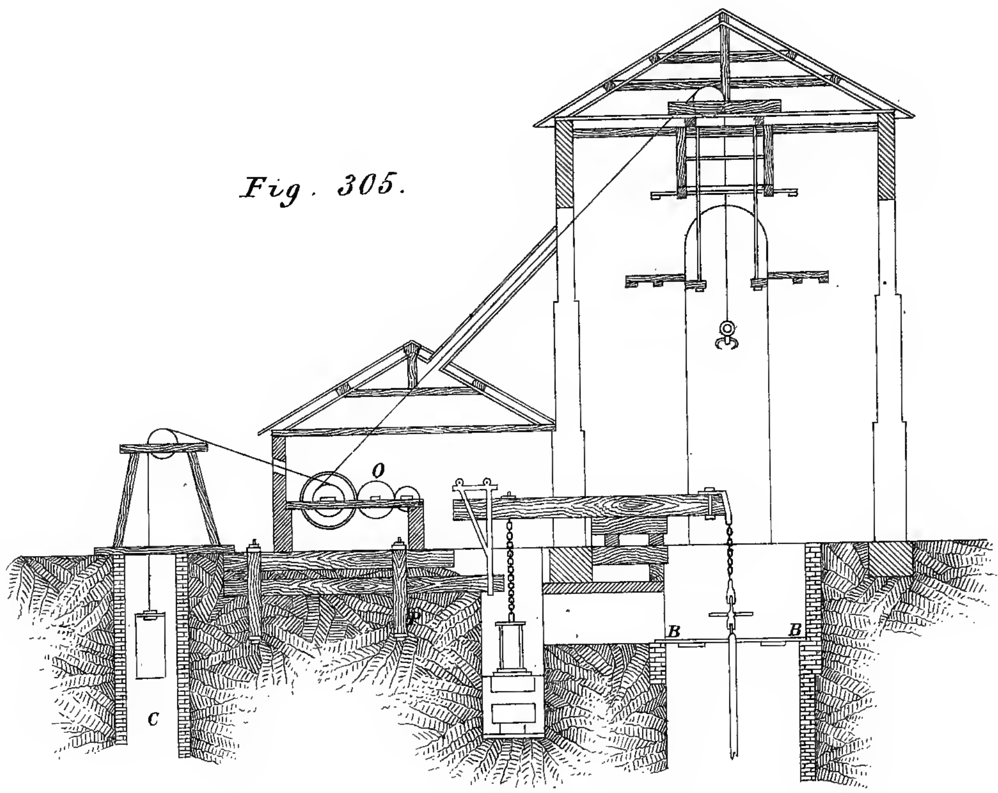
INCHES 12 6 0 1 2 FEET

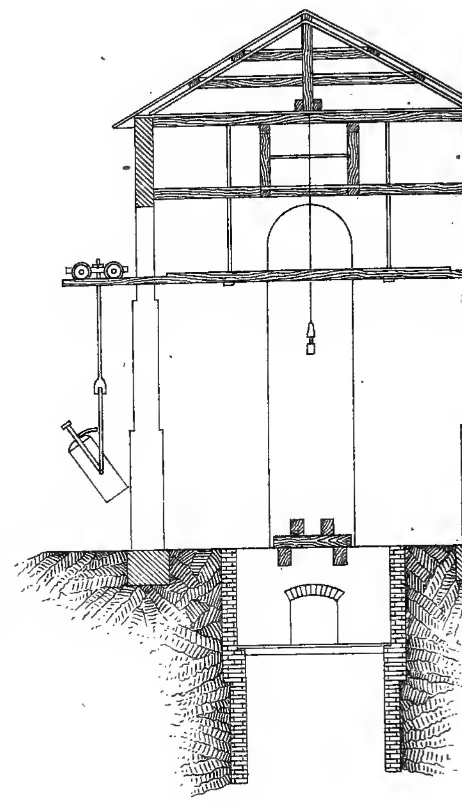
G. G. ANDRÉ.

don & New York.

KIND - CHAUPRON E

Fig. 305.





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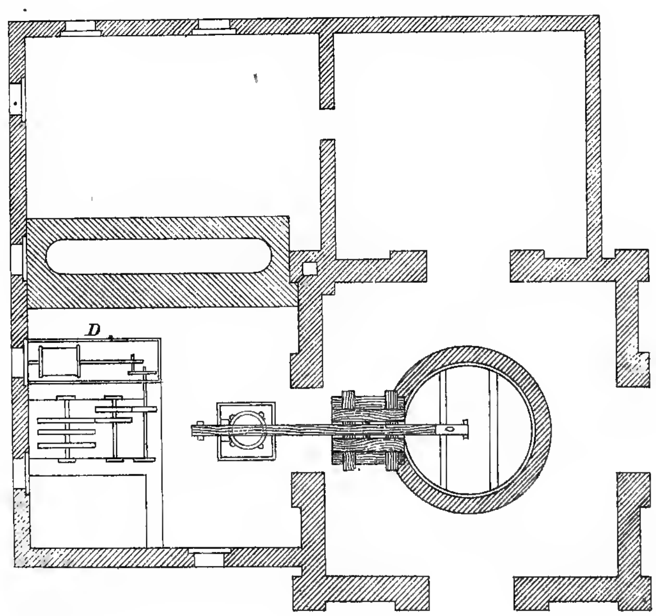
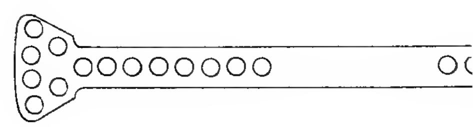


Fig. 323



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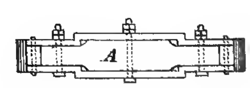

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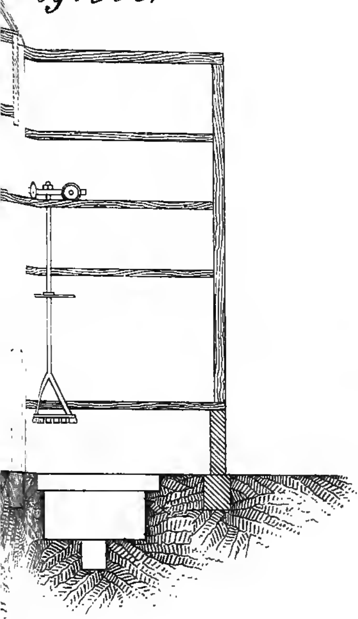
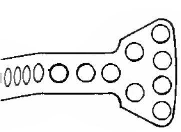
INCHES 12 6 0 1 2 3 4 5

BORING APPARATUS.

Fig. 306.





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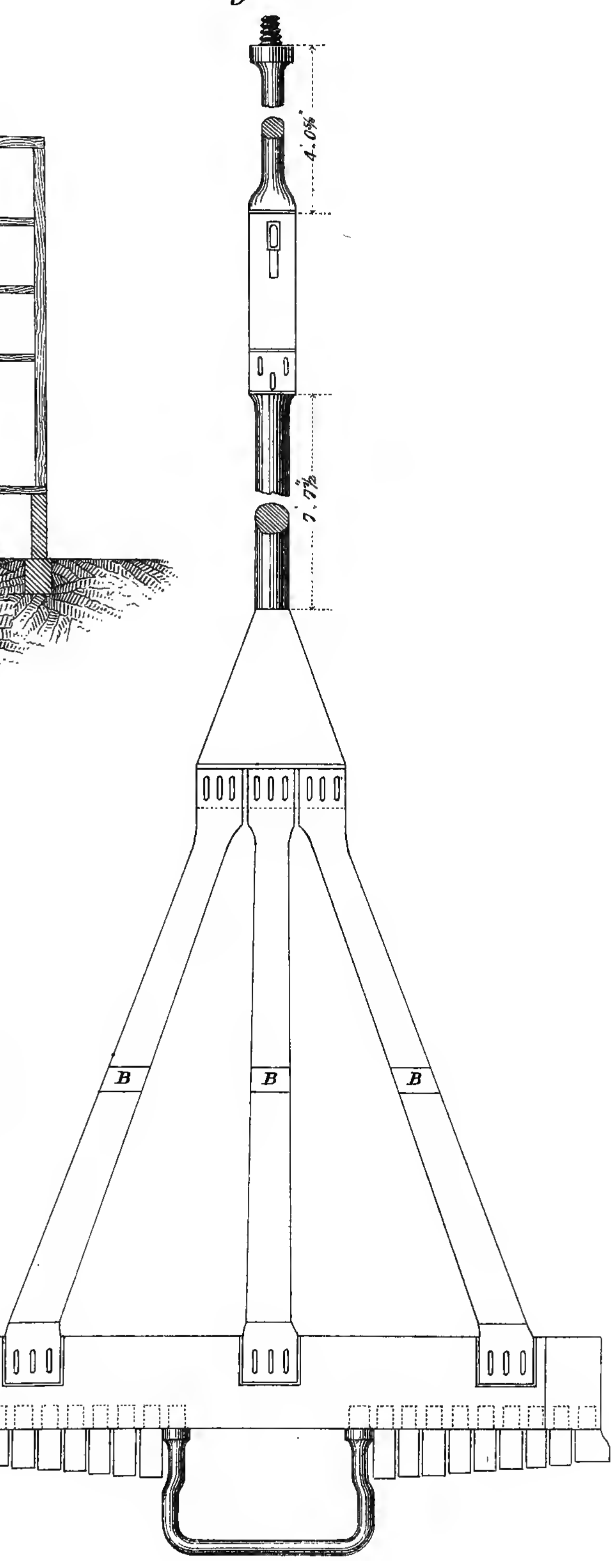
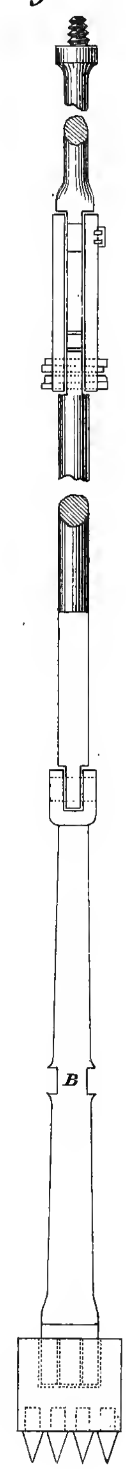


Fig. 322.



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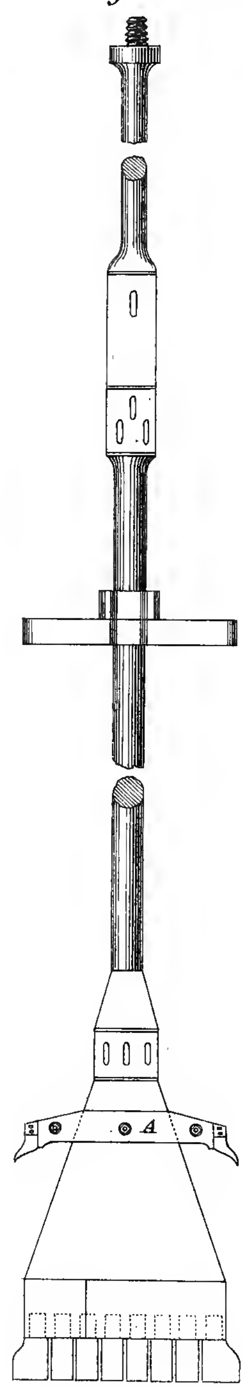
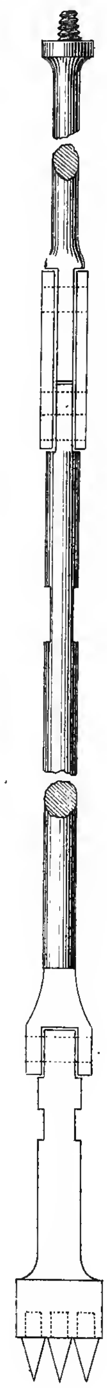


Fig. 309.



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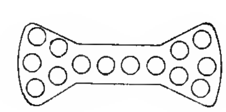

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308 TO 323.

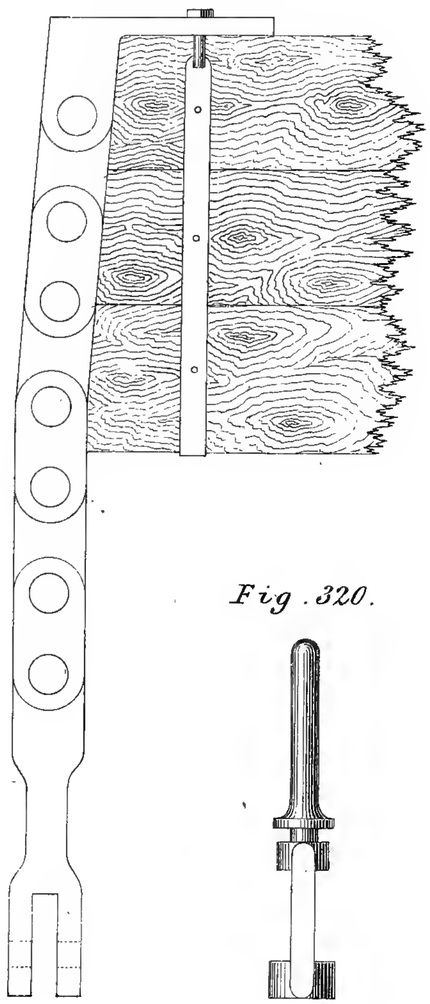
10 15 20 FEET.

G. G. ANDRÉ.

London & New York.

KIND – CHAUDRON BORI

Fig. 312.



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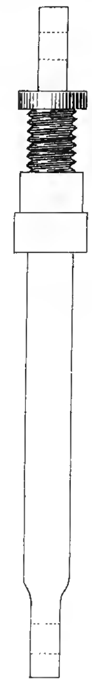

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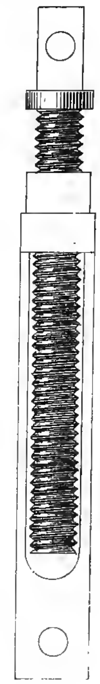

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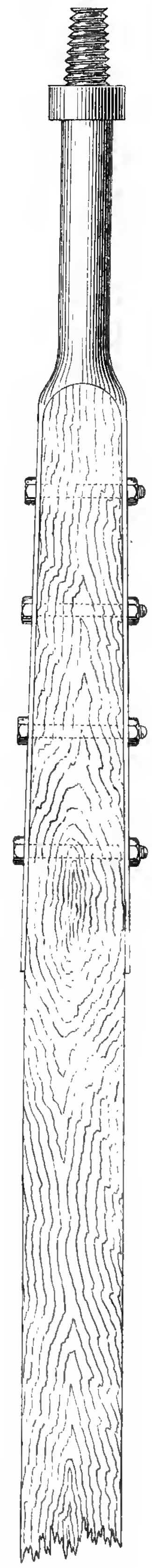

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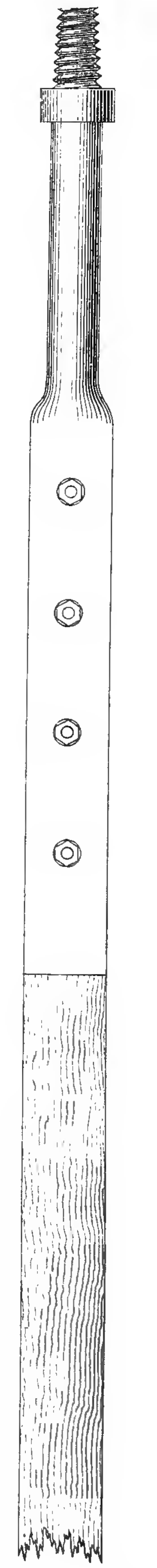
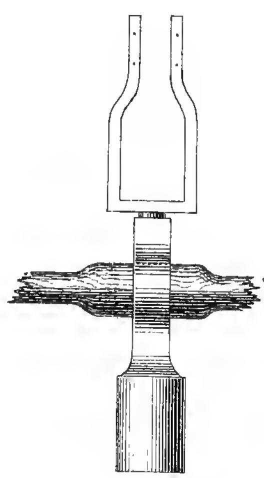


Fig. 320.

Fig. 315.



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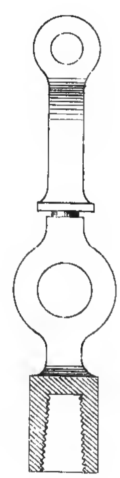
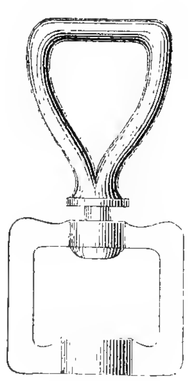


Fig. 319



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APPARATUS — Details.

Fig. 324.

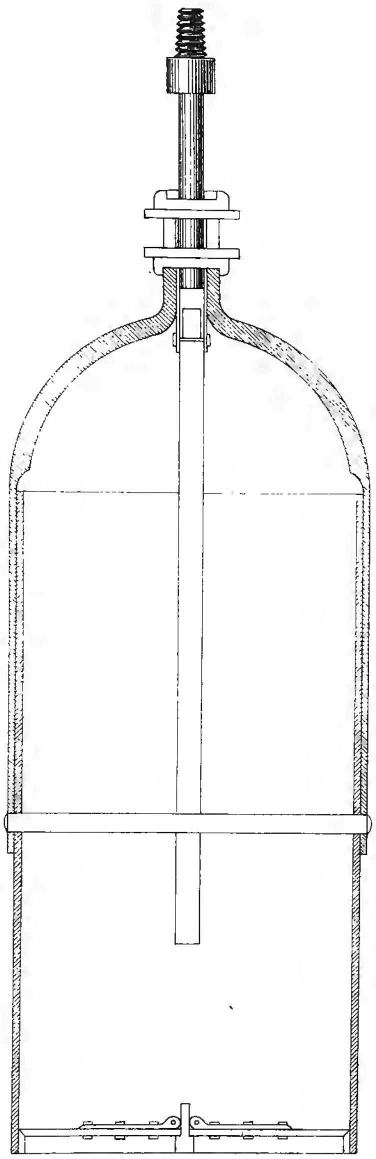
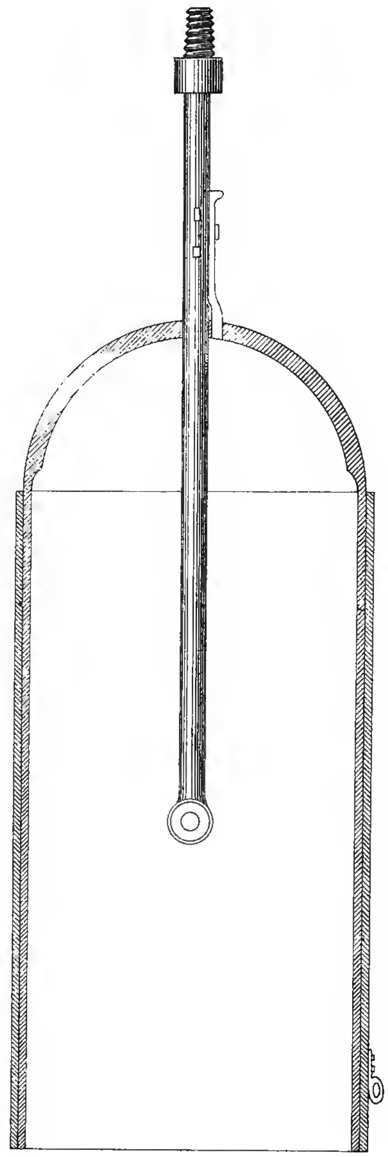


Fig. 325.



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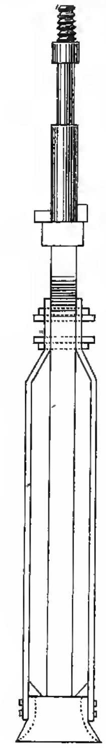

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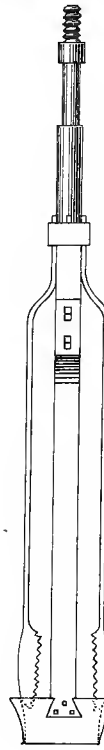

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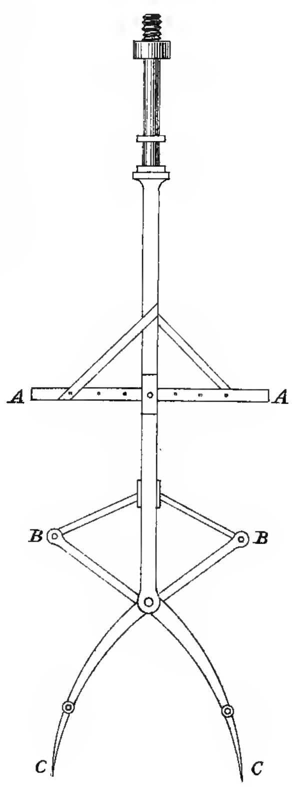
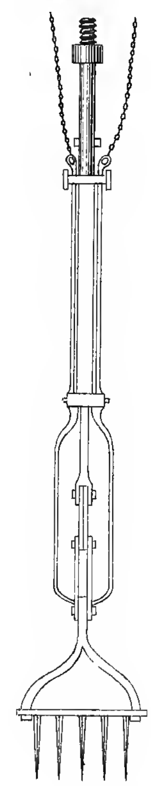


Fig. 330



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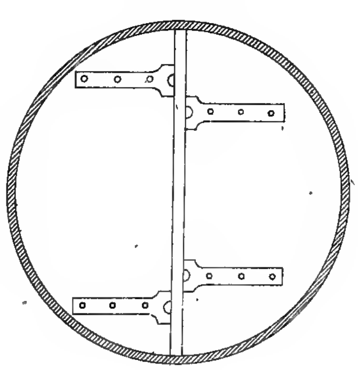
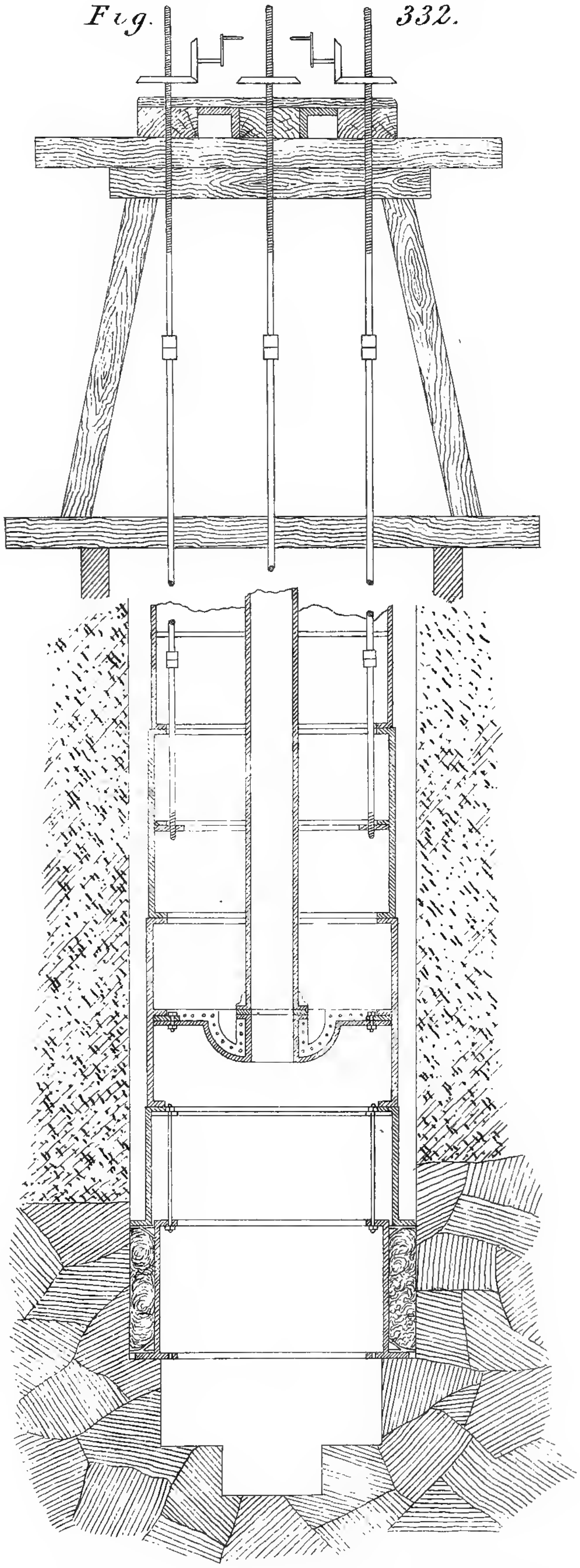


G.G.ANDRÉ.

KIND-CHAUDRON BORING APPARATUS — Details.

Fig. 332.



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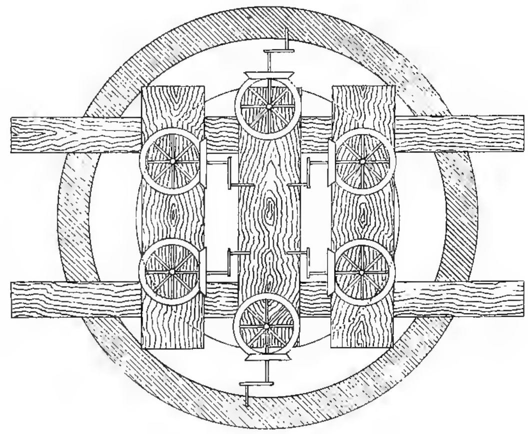

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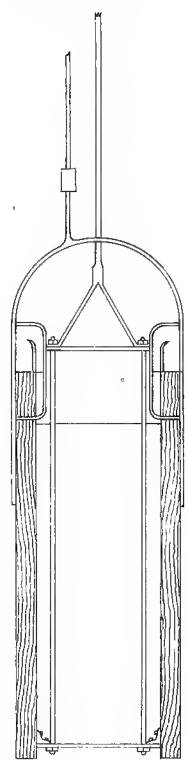
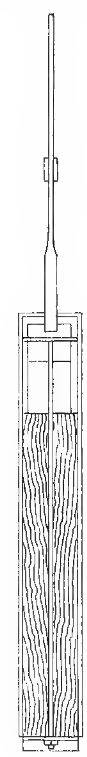


Fig 334.



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COAL CUTTING MACHI

Fig. 335.

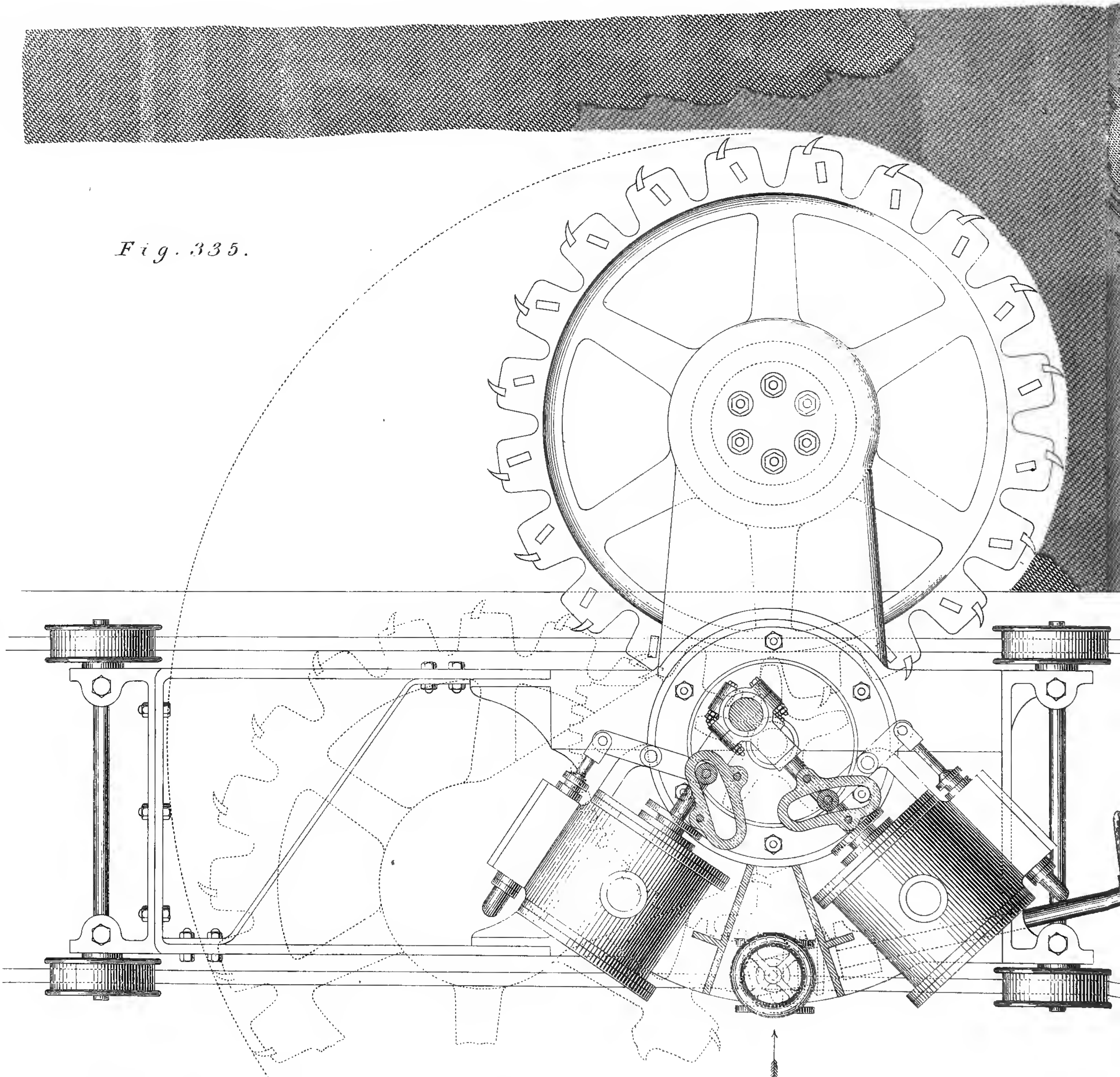

Fig. 342

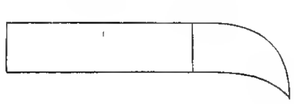

Fig. 341.

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FIGS 335-

INCHES 12 9 6 3 0 1 2 FIGS 335-

E & F.N. Spon. Londo

NES —— WINSTANLEY AND BARKER.

Fig 336.

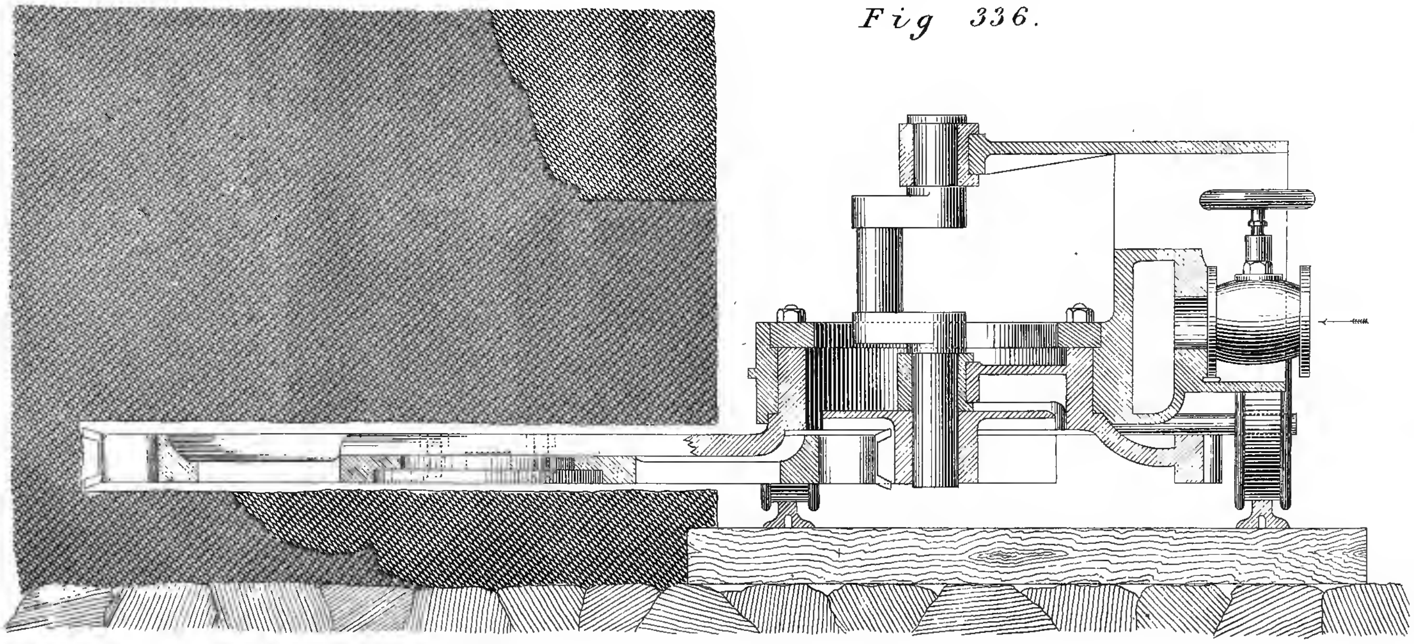


Fig. 337.

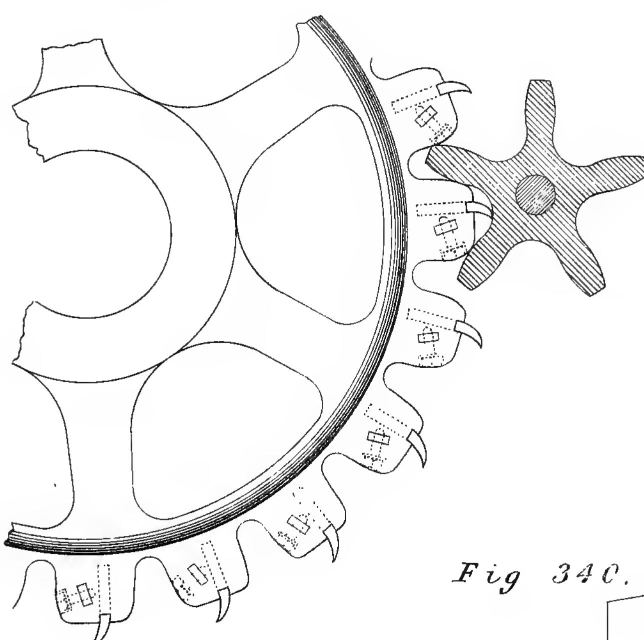


Fig. 338.

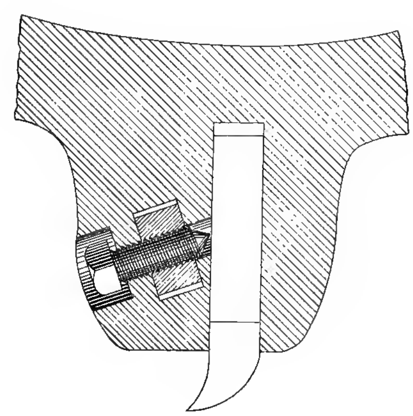
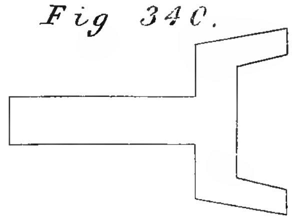


Fig 340.



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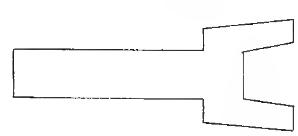

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8 – 342.

7 8 9 10 11 12 INCHES

– 337.

3 4 5 6 FEET.

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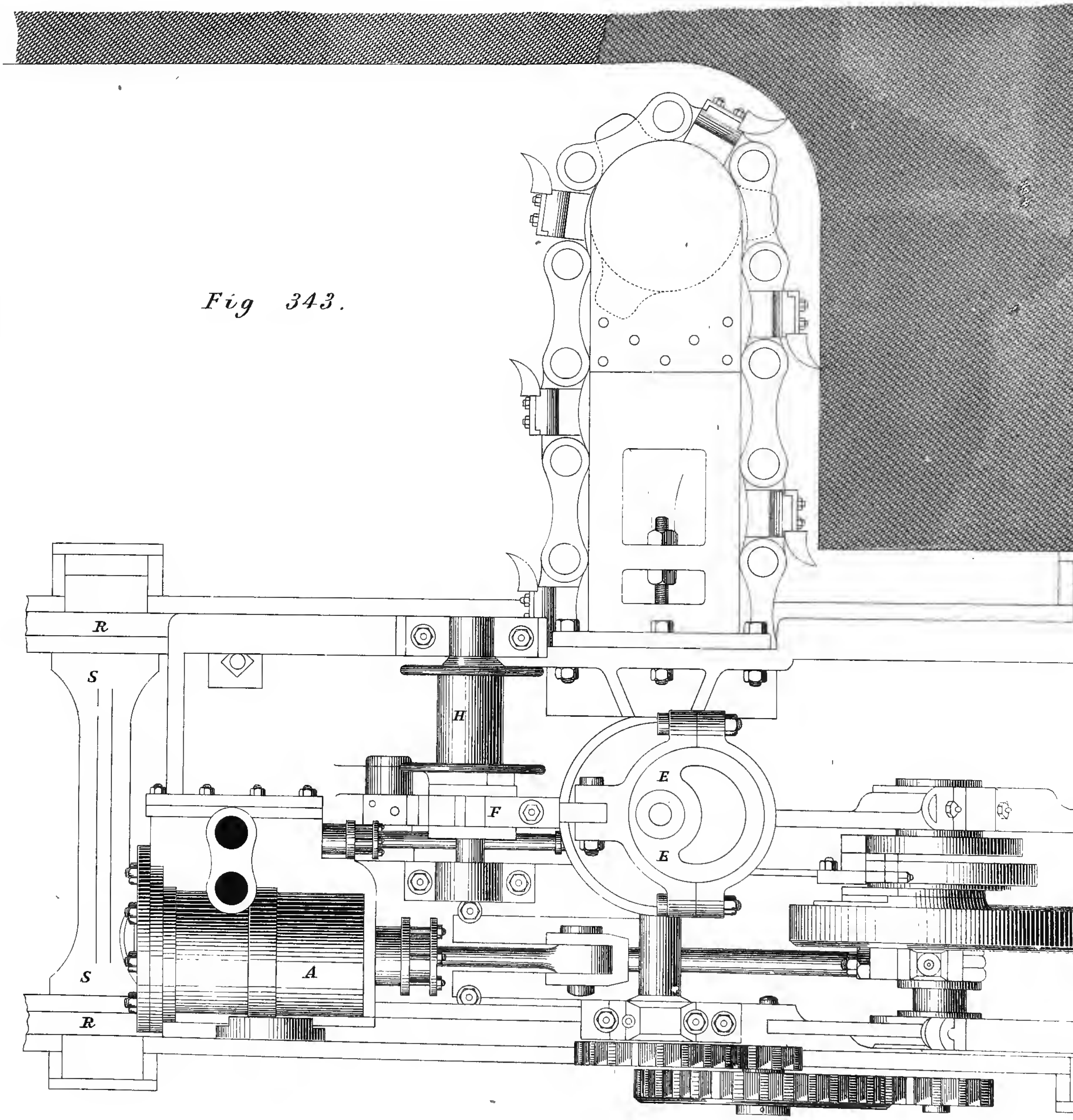
don & New York.

COAL CUTTING

Fig 343.



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INCHES 12 9 6 3 0 1 2 3

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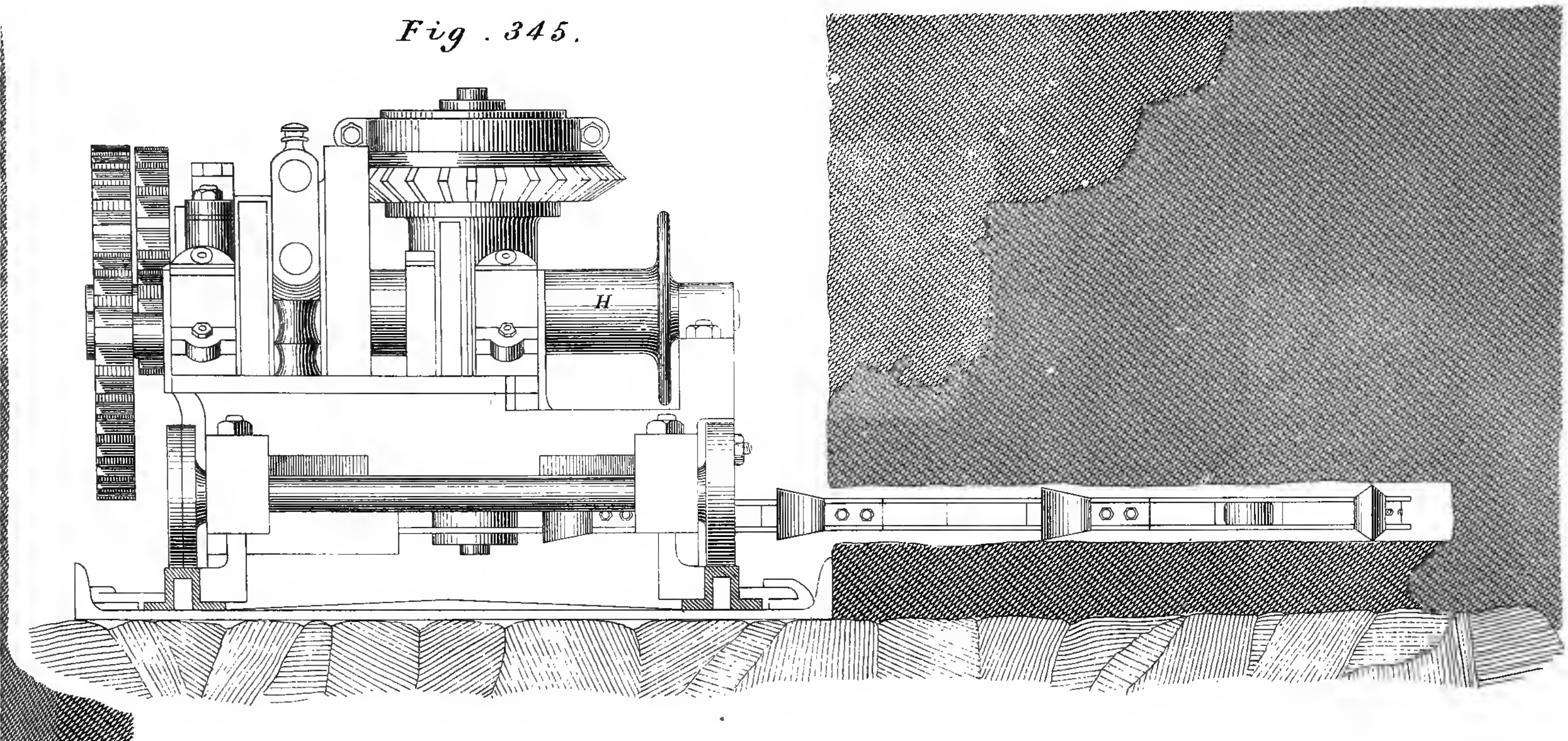
MACHINES — BAIRD

Fig. 345.



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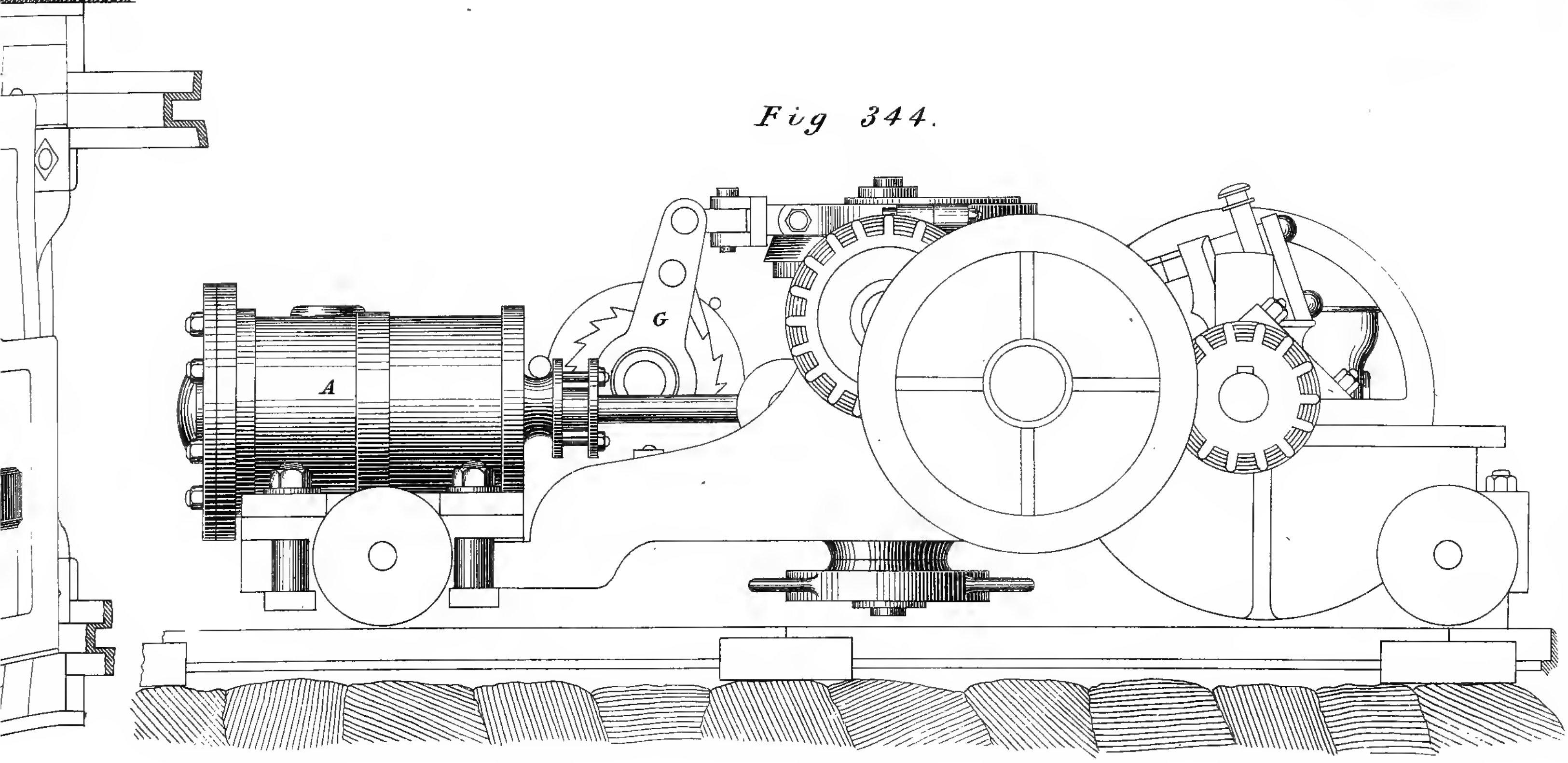

A L E.

4 5 6 7 8 FEET.

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COAL CUTTING MACHINES — GILLOTT AND COPLEY.

Fig 346.

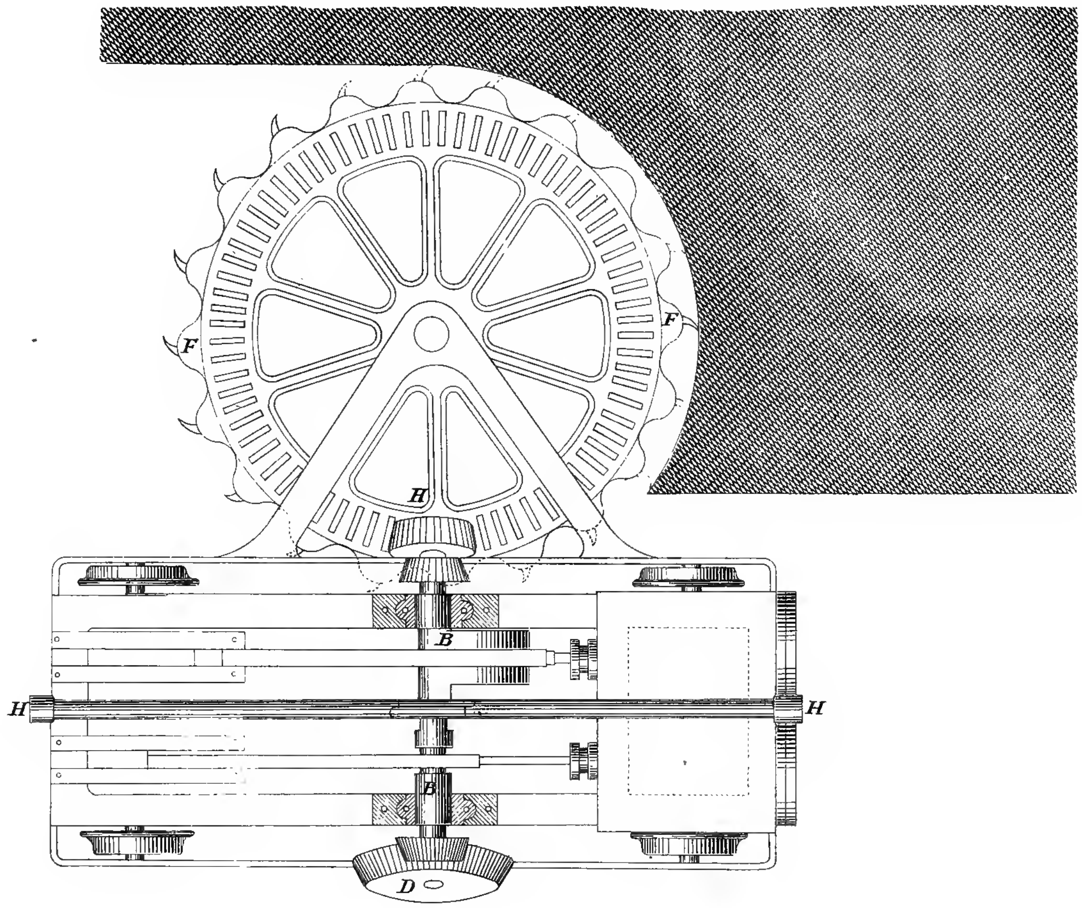
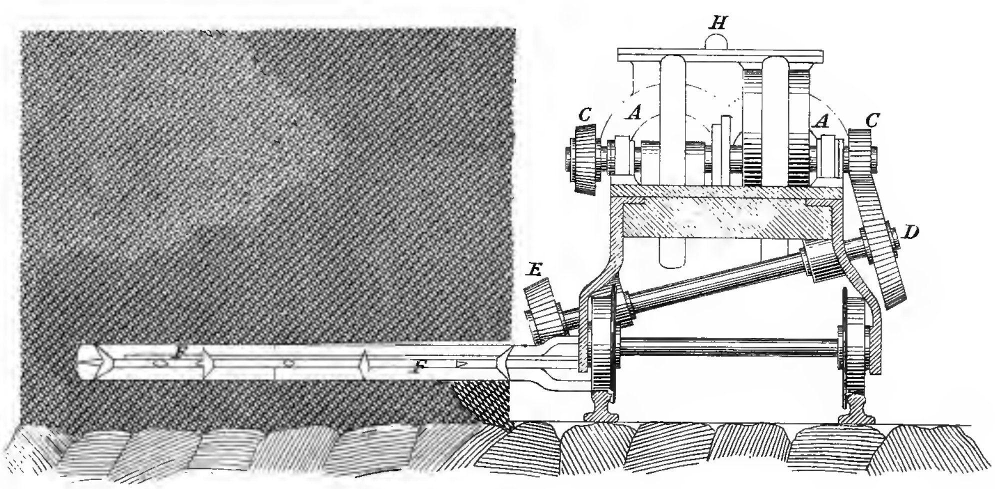
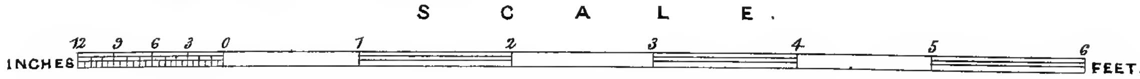


Fig 347



S C A L E.



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COAL CUTTING MACHINES — ECONOMIC.

Fig. 348.

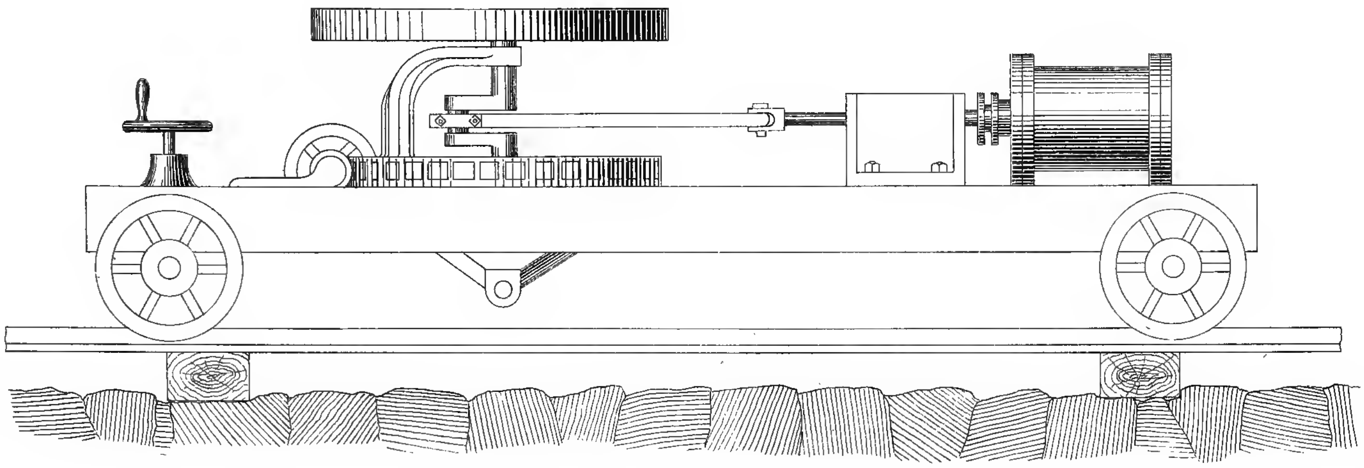


Fig. 349.

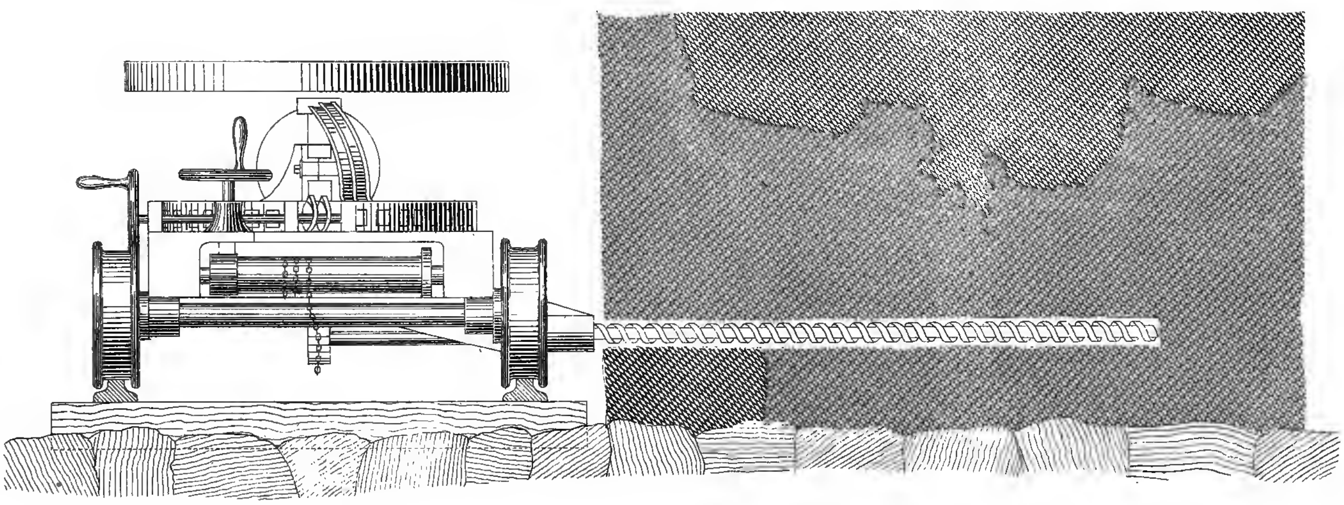


Fig. 350.

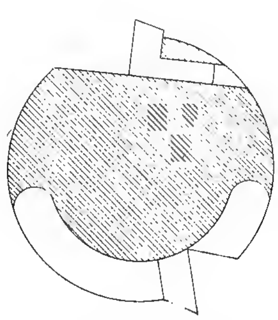
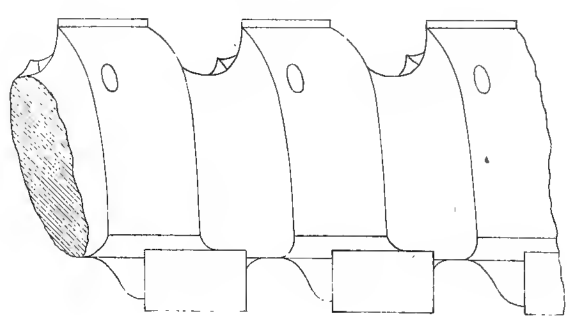


Fig. 351



G. G. ANDRÉ.

E & F.N. Spon. London & New York.

COAL CUTTING MA

Fig. 352.

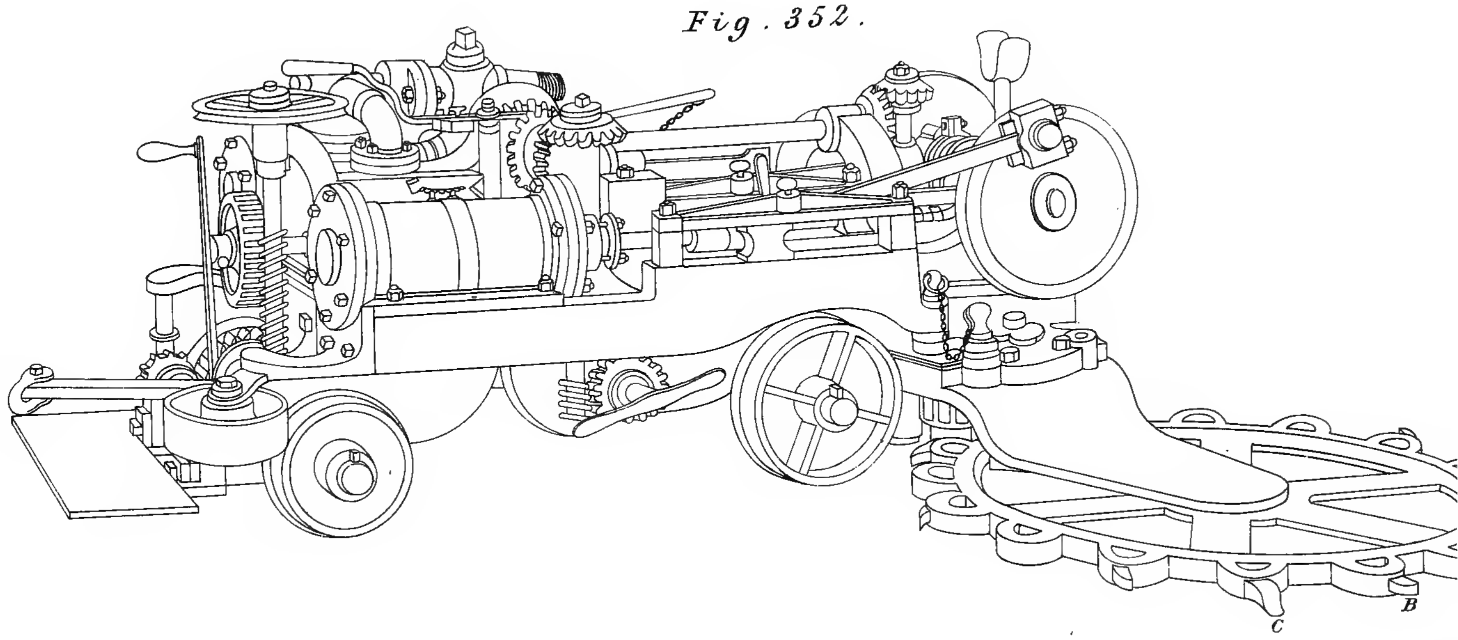
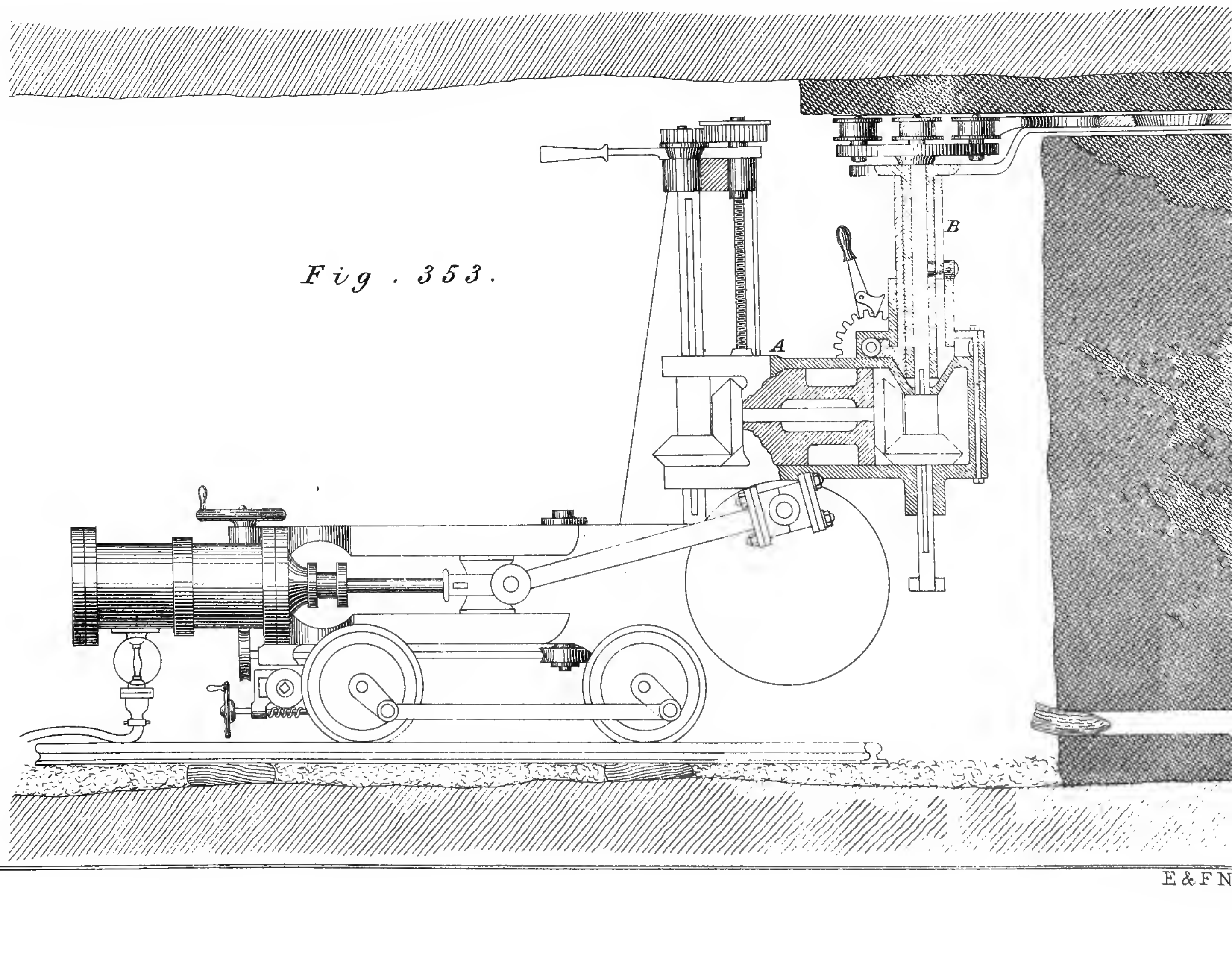


Fig. 353.



E&FN

ACHINES — HURD AND SIMPSON.

Fig. 356.

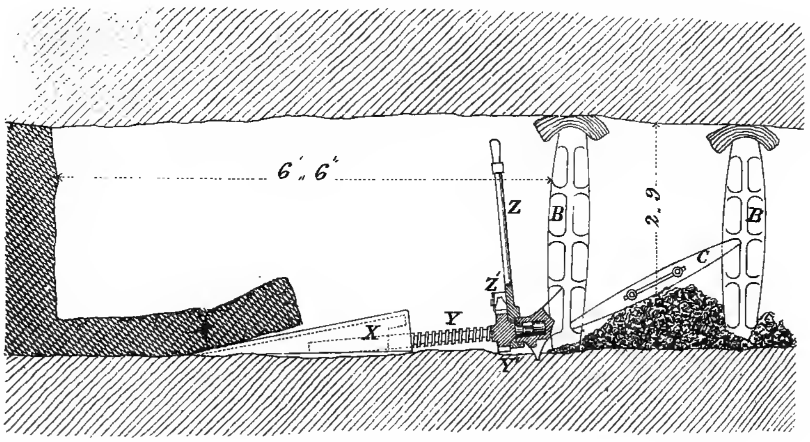
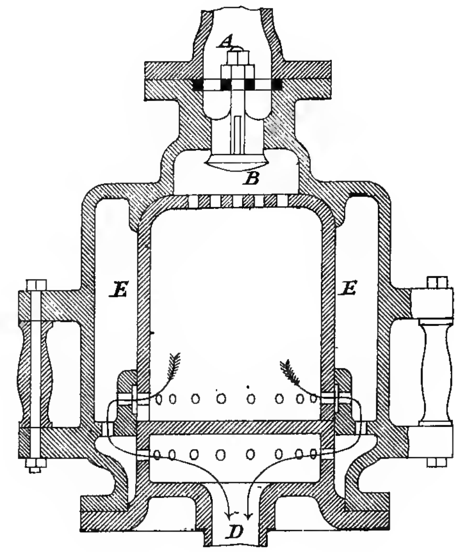


Fig. 355.



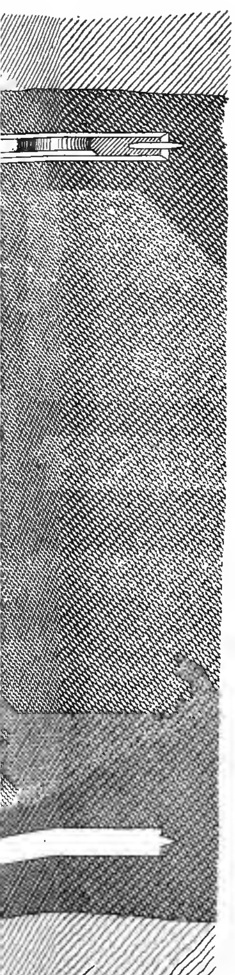
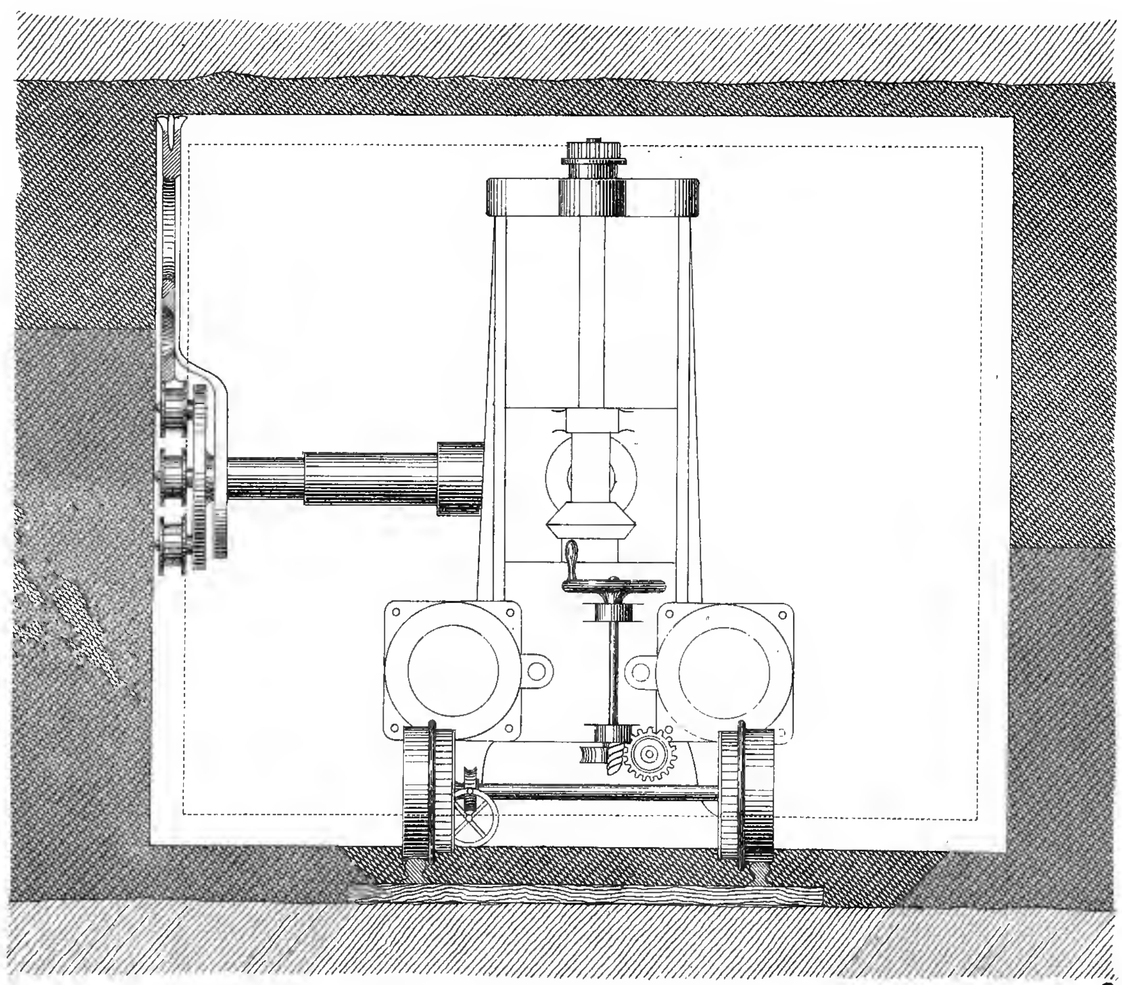


Fig. 354.



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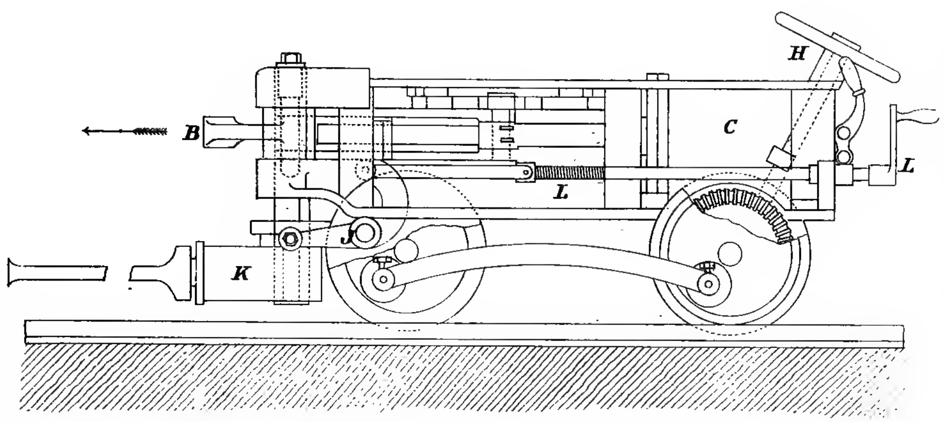
COAL CUTTING MACHINES — FIRTH.

Fig 257.



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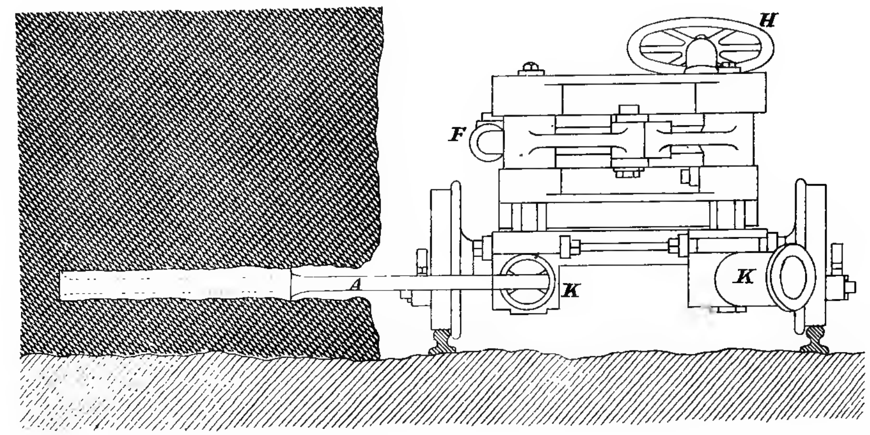


Fig. 259.

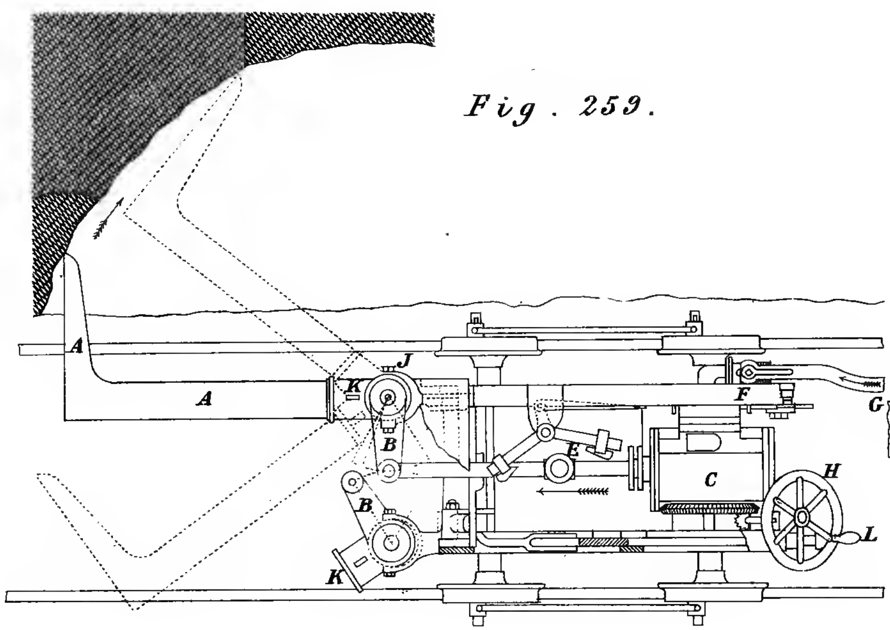
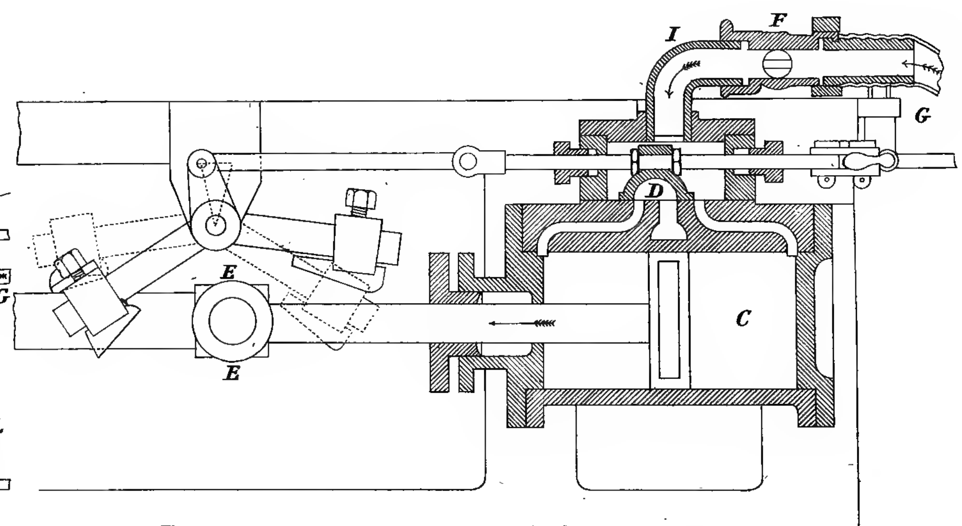


Fig. 260



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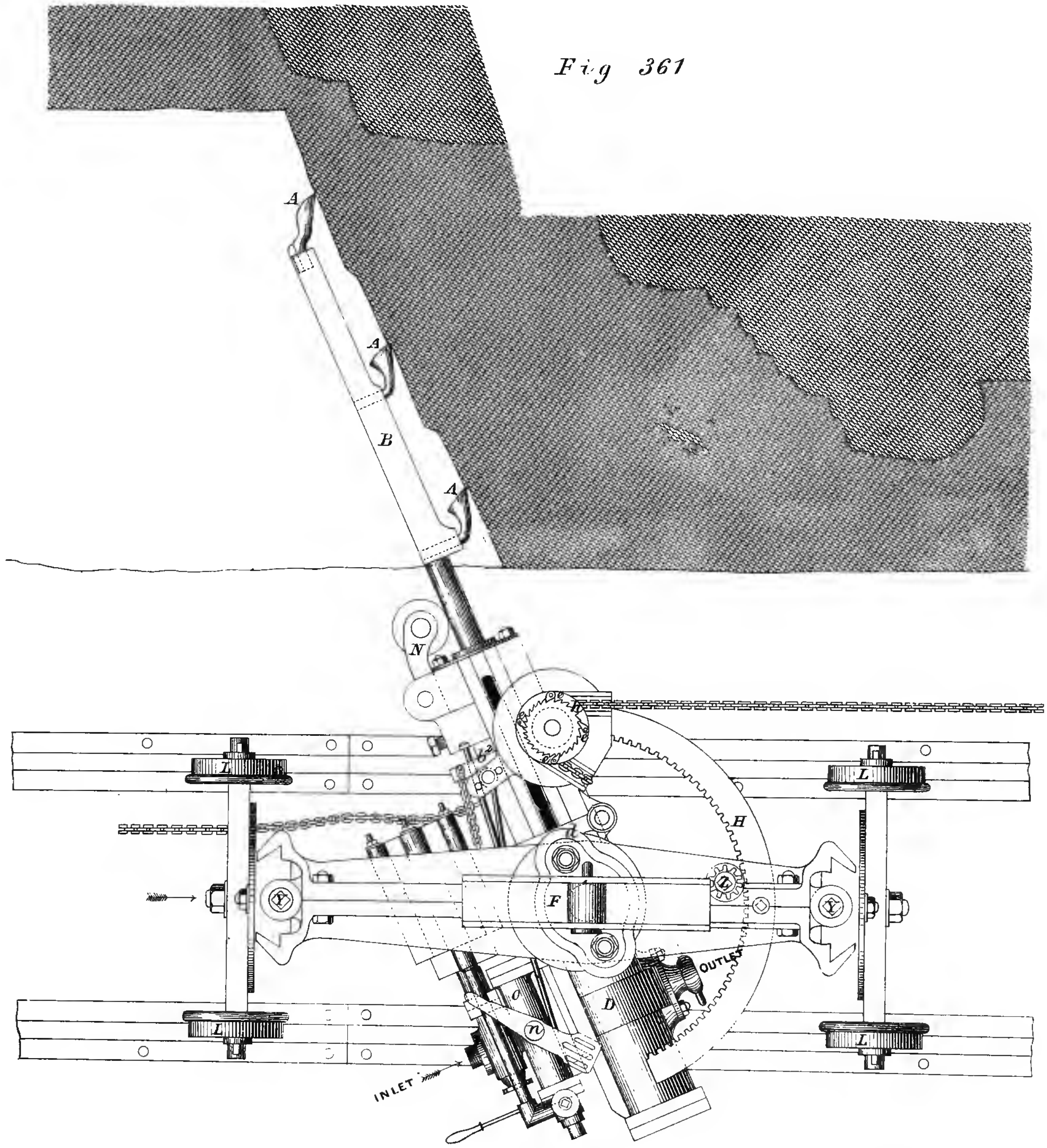
E & F.N. Spon, London & New York.

COAL CUTTING MACHINES — CARRETT

Fig 361



SCALE.

INCHES 12 9 6 3 0 1 2 3 4 5

ND MARSHALL. COAL FALLING MACHINE.

Fig. 362

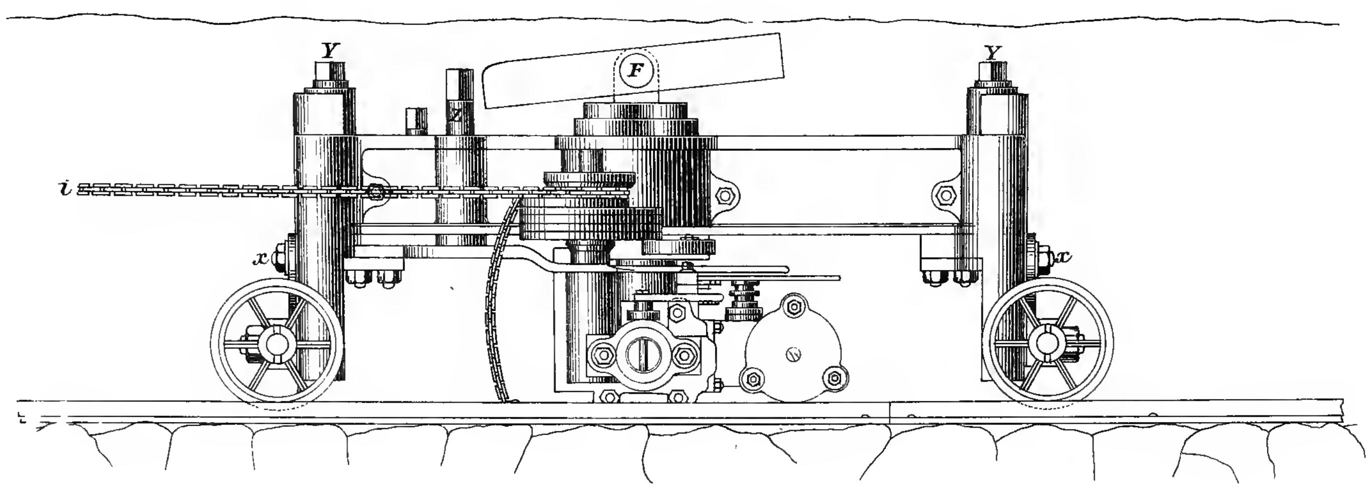


Fig. 363.

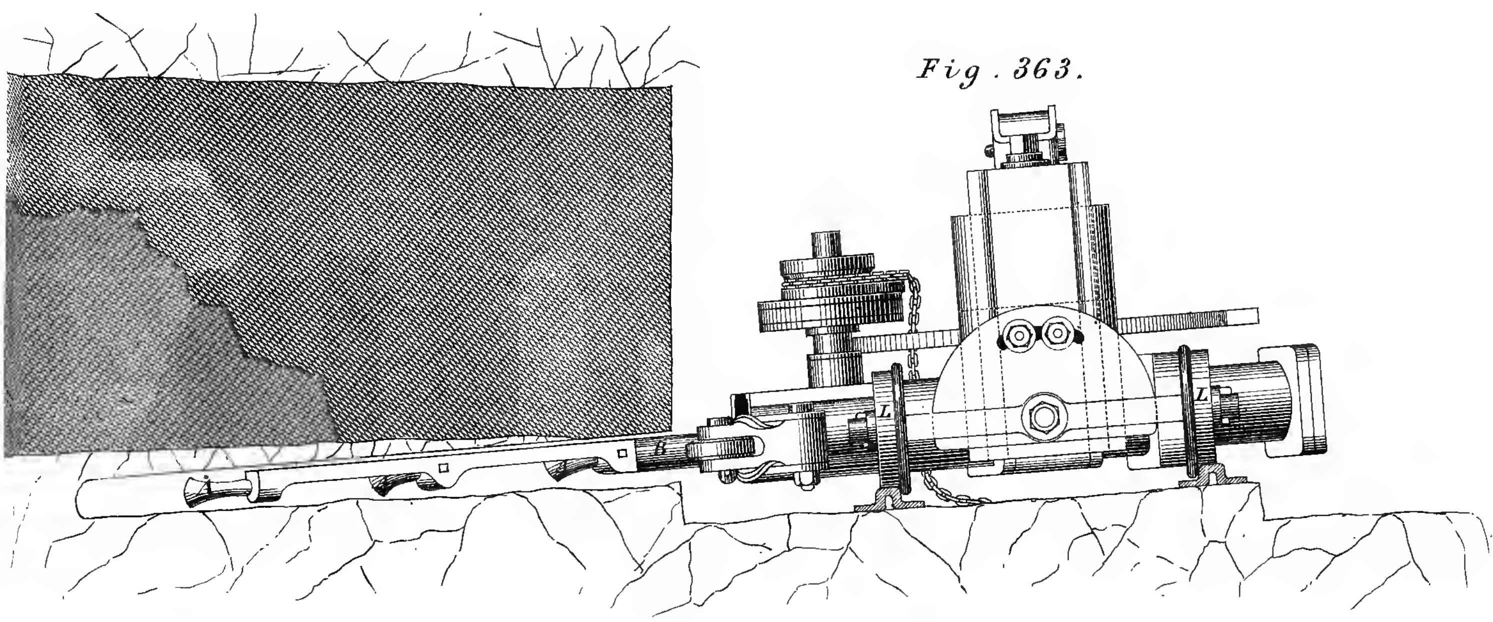
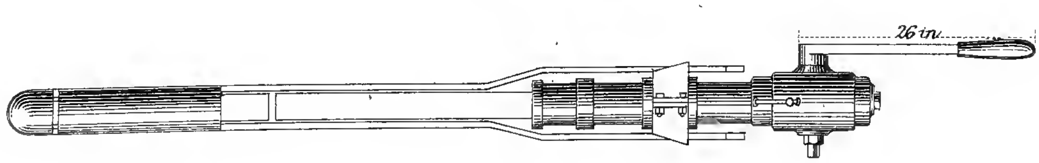


Fig. 364.



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WHEEL-FLANGES AND WOODEN TUBS.

Fig. 365.

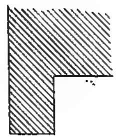


Fig. 366.

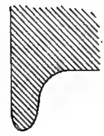


Fig. 367.

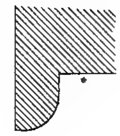


Fig. 368.

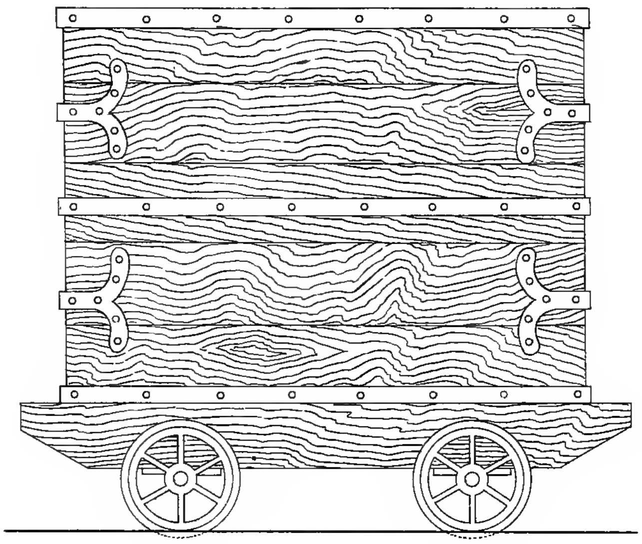


Fig. 370.

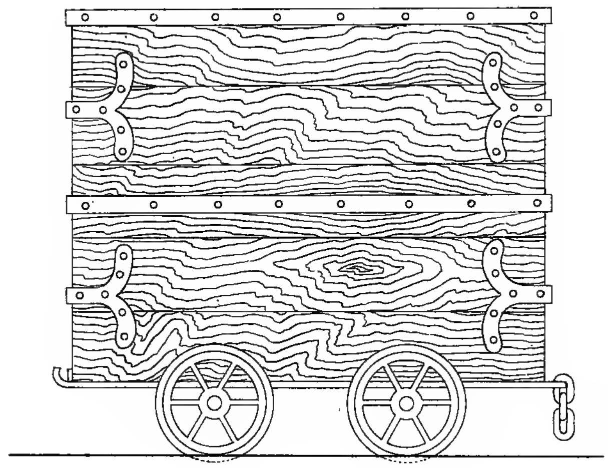


Fig. 369.

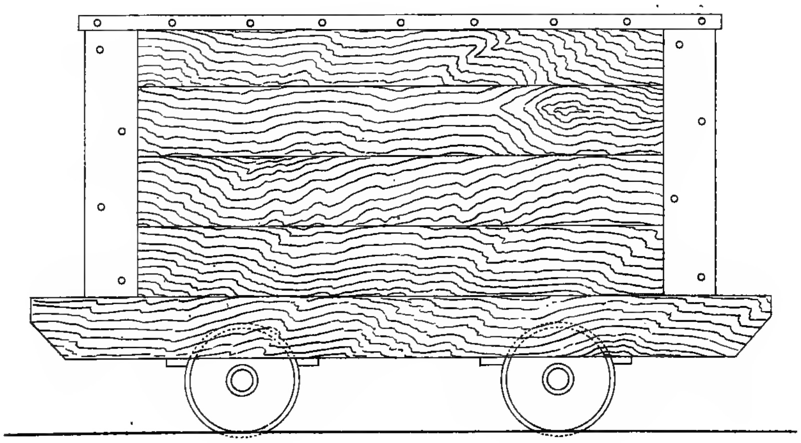
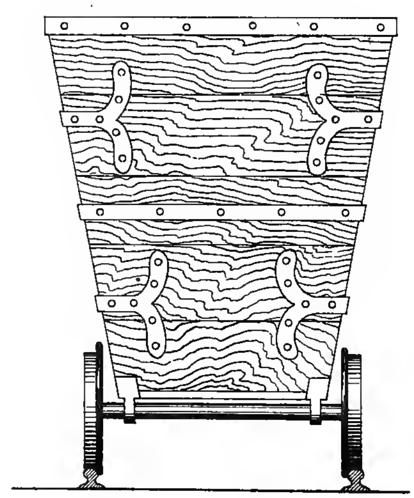
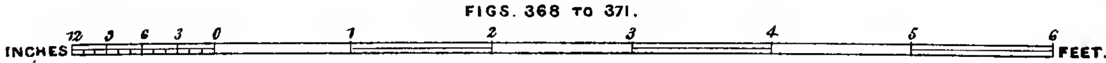


Fig. 371.



SCALE.

FIGS. 368 TO 371.



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E & F.N Spon. London & New York.

WROUGHT IRON TU

Fig. 372.

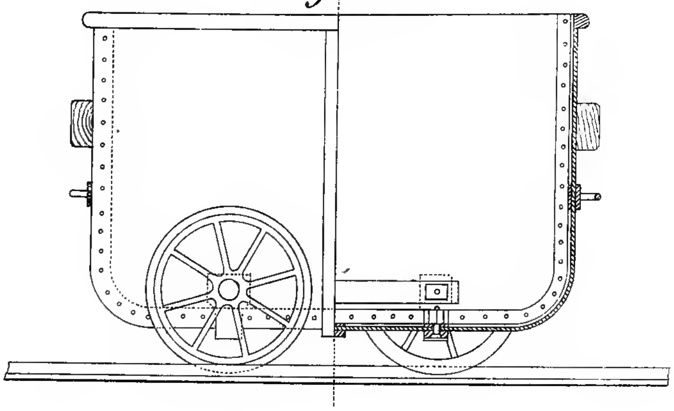
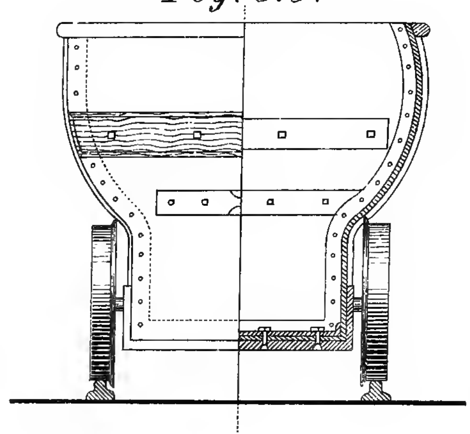


Fig. 373.



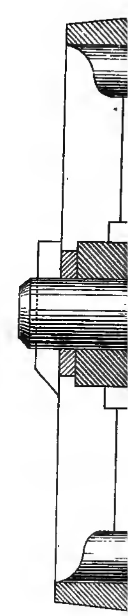


Fig. 374.

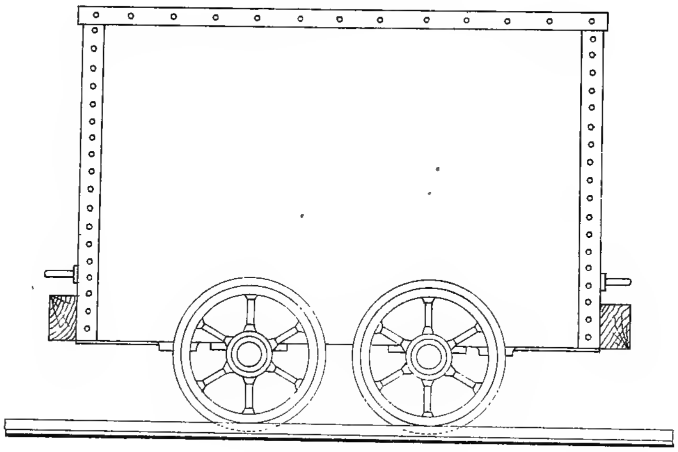
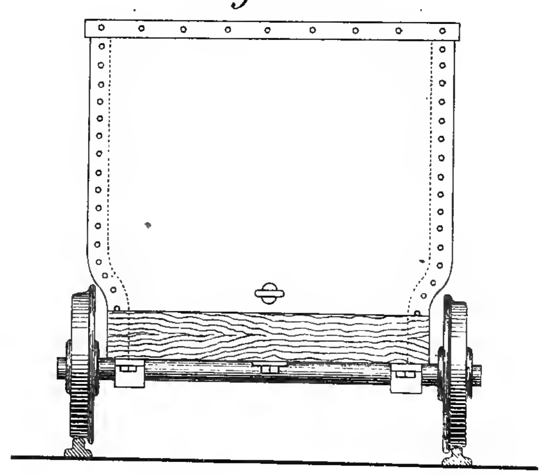


Fig 375.



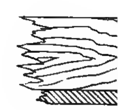


Fig. 378.

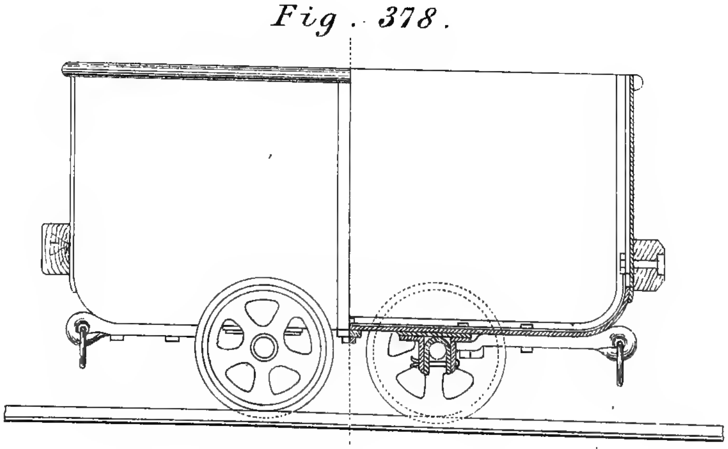
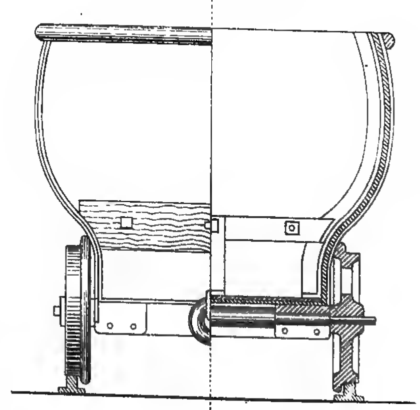


Fig. 379.



INCHES

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S AND TUB WHEELS.

ig. 376.

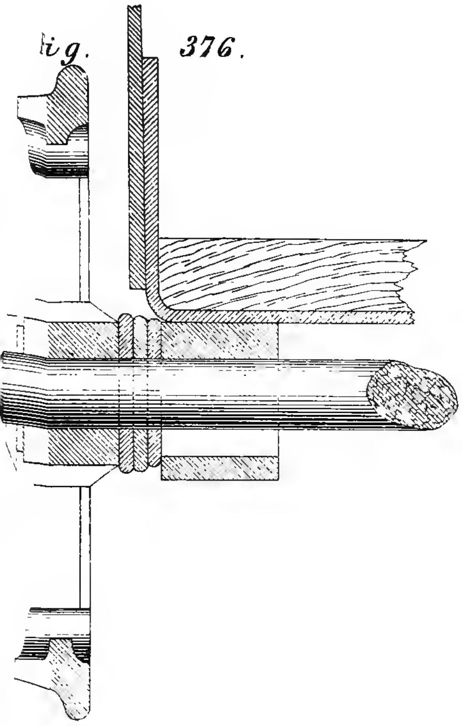


Fig. 380.

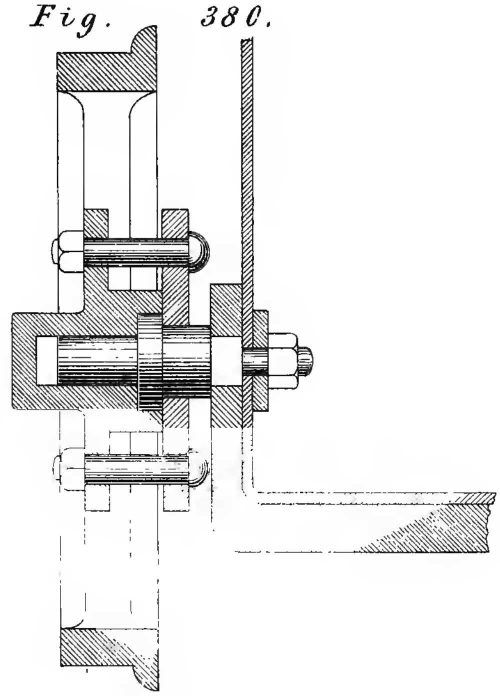


Fig. 381.

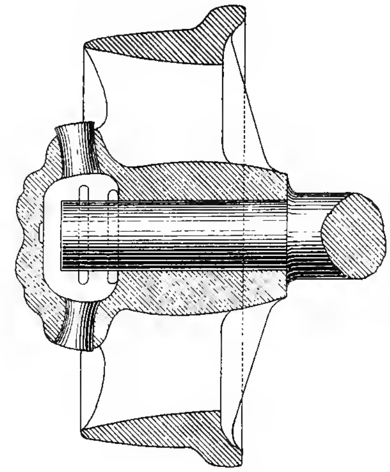
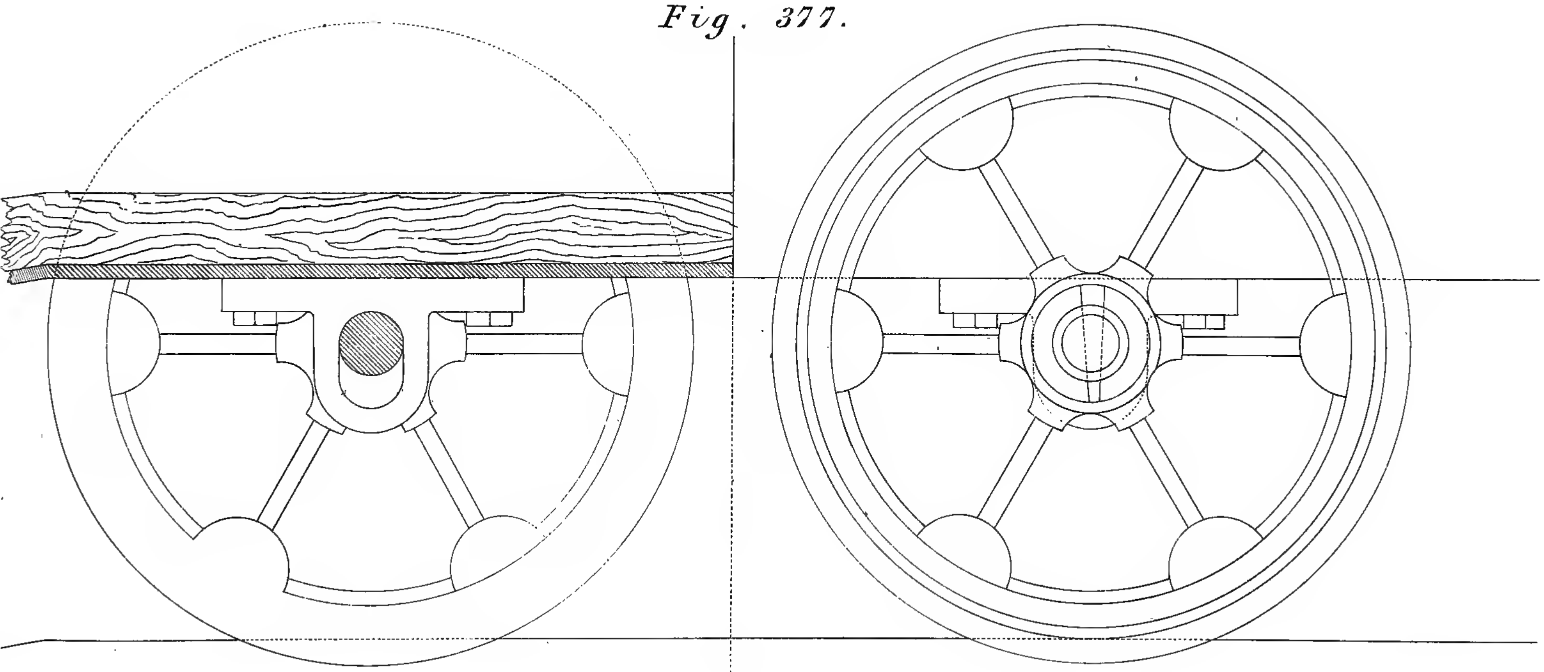
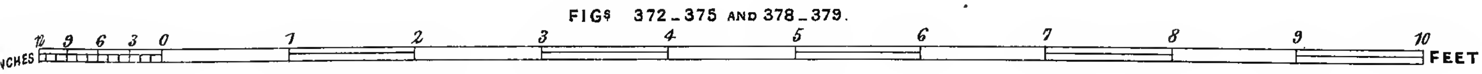


Fig. 377.

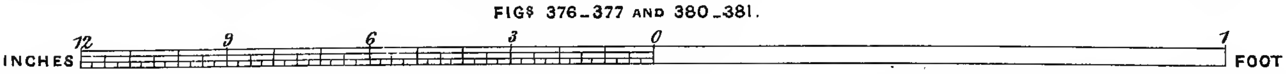


SCALES.

FIGS 372_375 AND 378_379.



FIGS 376_377 AND 380_381.



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WROUGHT IRON TUBS.

Fig. 382.

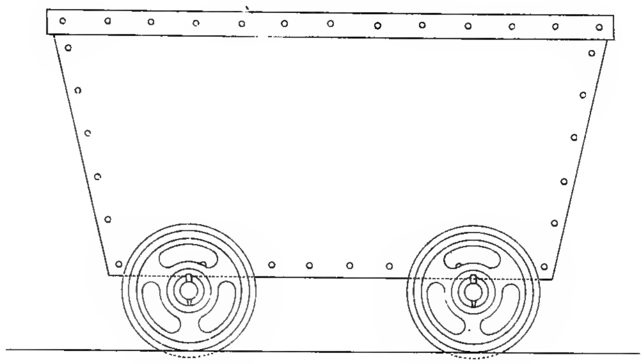


Fig 383.

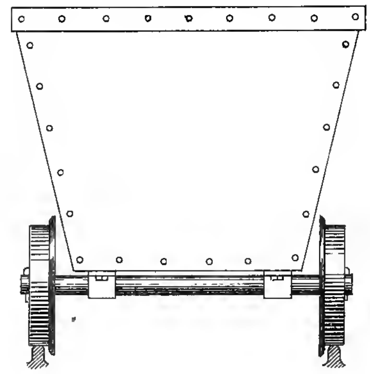


Fig. 384.

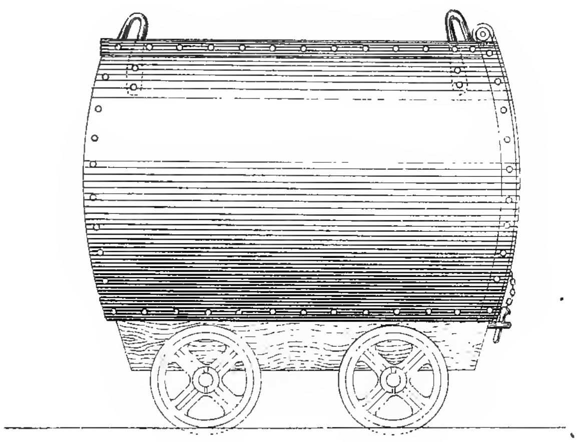


Fig 385.

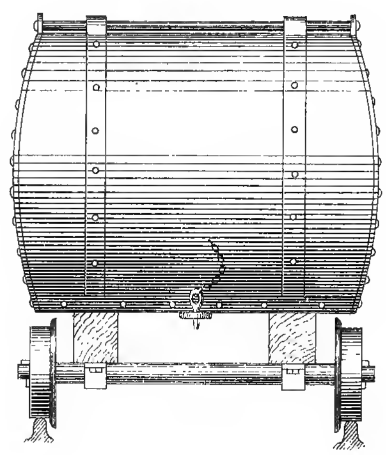


Fig. 386.

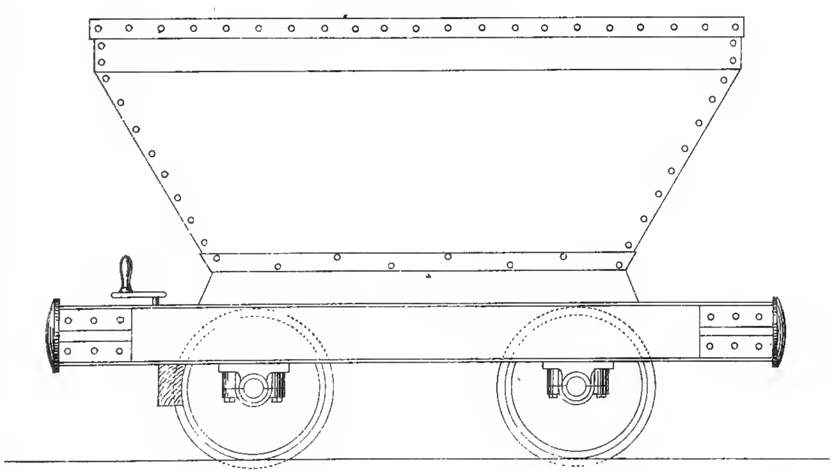
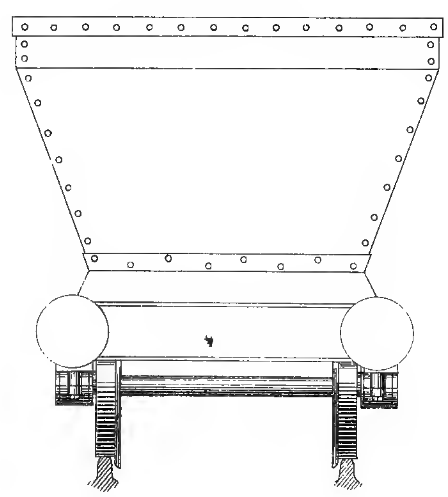


Fig 387.



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WROUGHT IRON TUBS AND TIPPING TUBS.

Fig. 388.

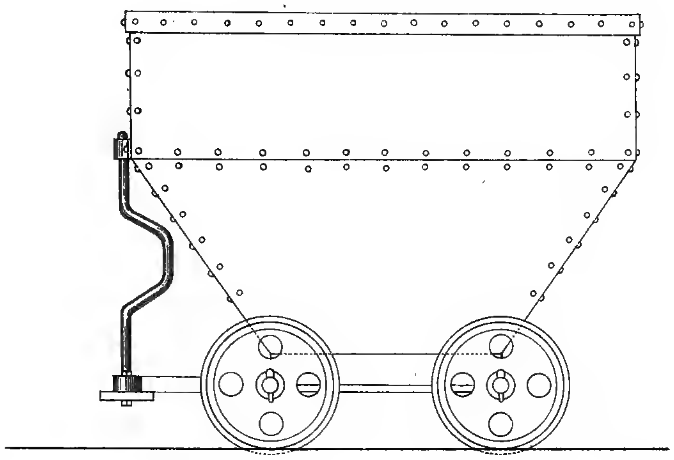


Fig. 389.

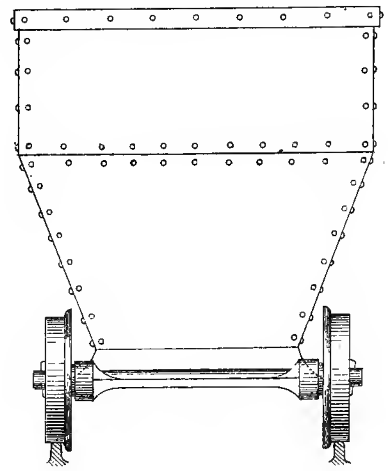


Fig. 390.

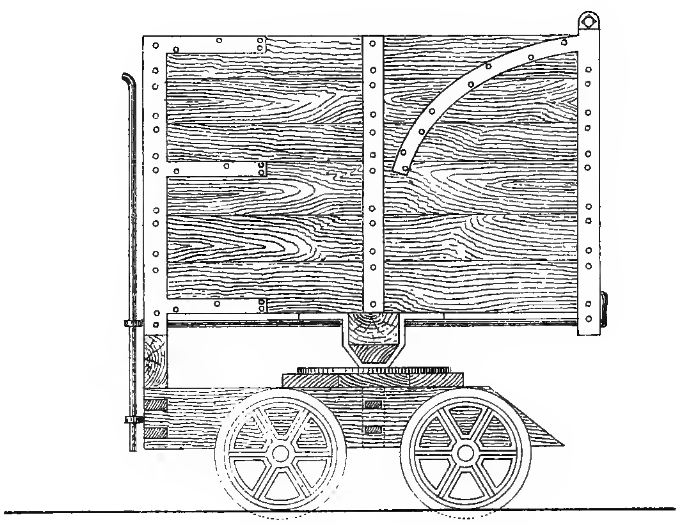


Fig. 391.

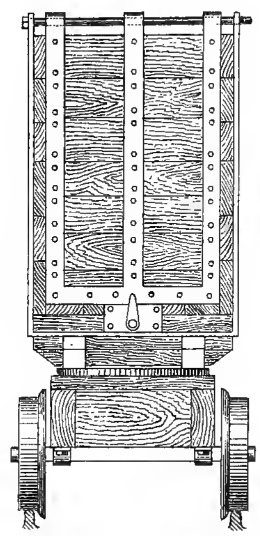


Fig. 392.

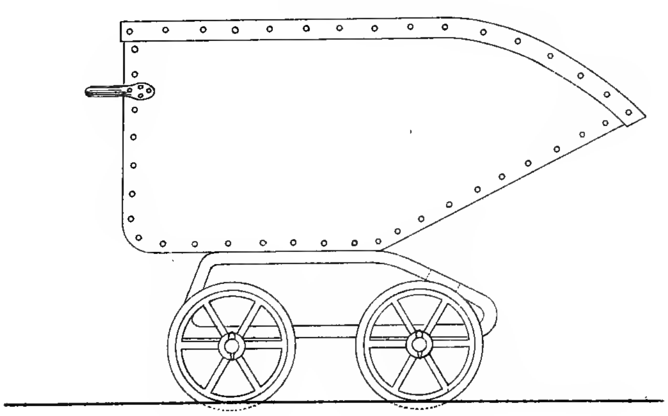
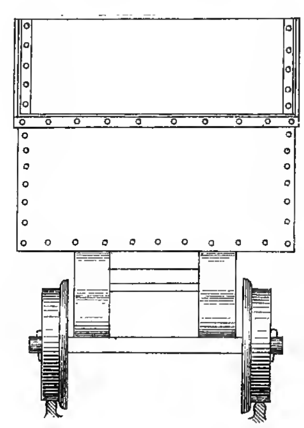


Fig. 393.



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WROUGHT IRON TIPPING TUBS.

Fig. 394.

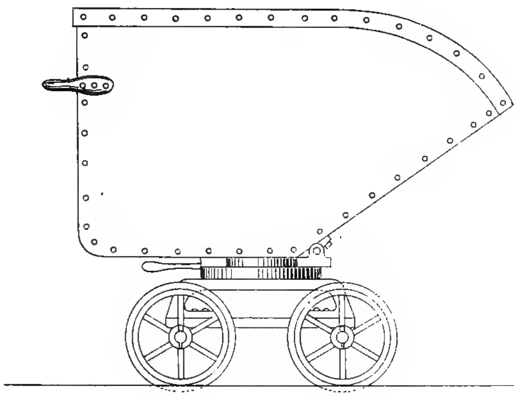


Fig. 395.

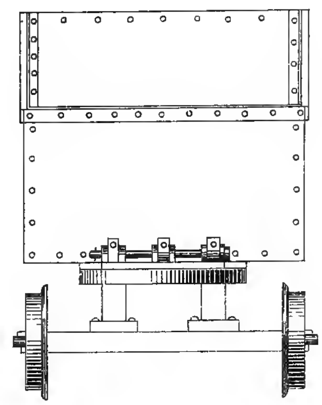


Fig. 396.

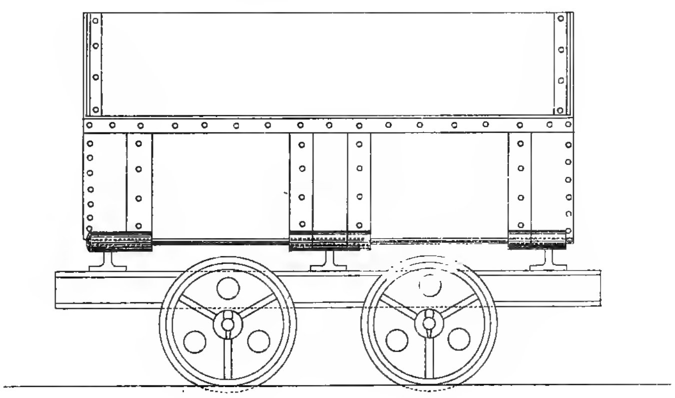


Fig. 397.

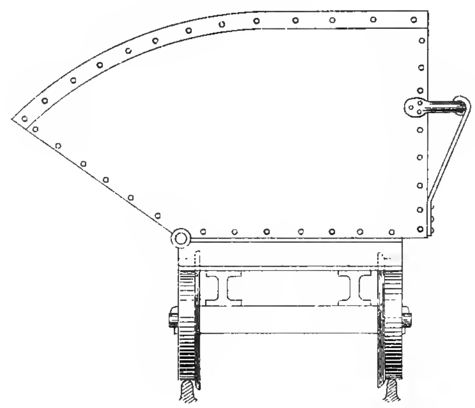


Fig. 398

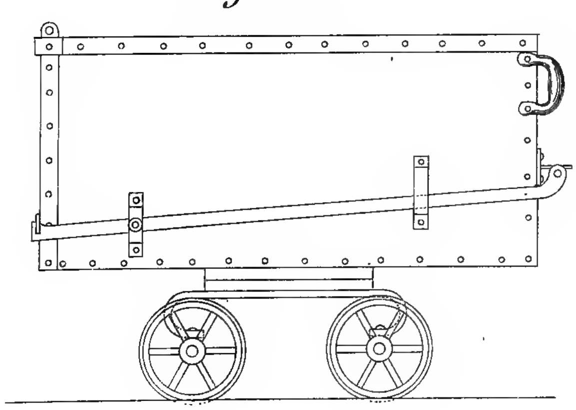
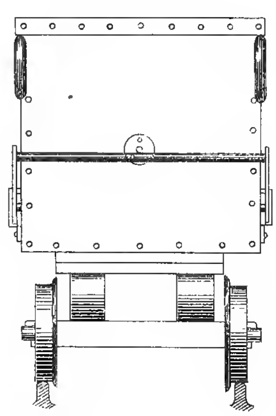


Fig. 399



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TIPPING CRADLES, JUNCT

Fig. 400.

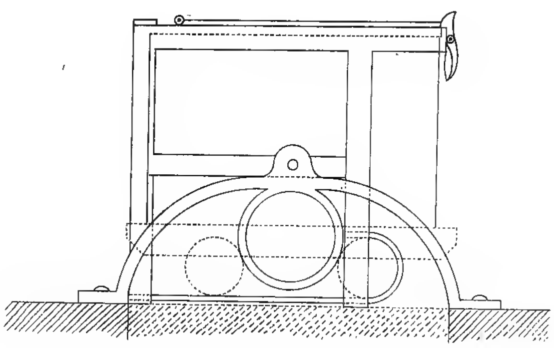


Fig. 401.

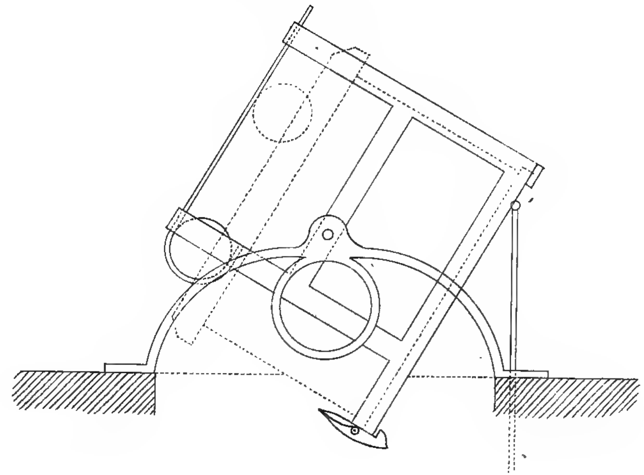
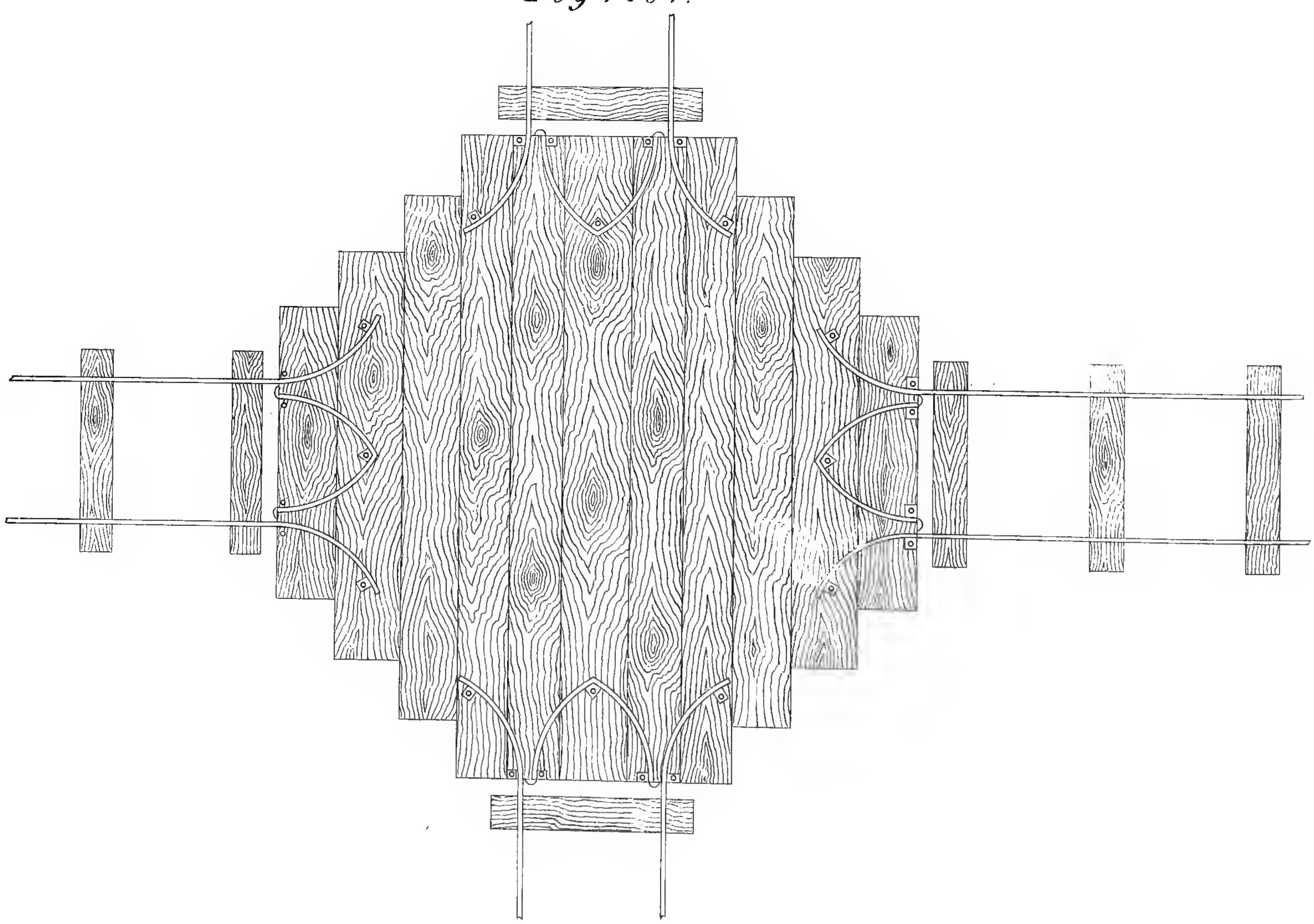


Fig. 404.



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IONS AND TURNTABLES.

Fig. 402.

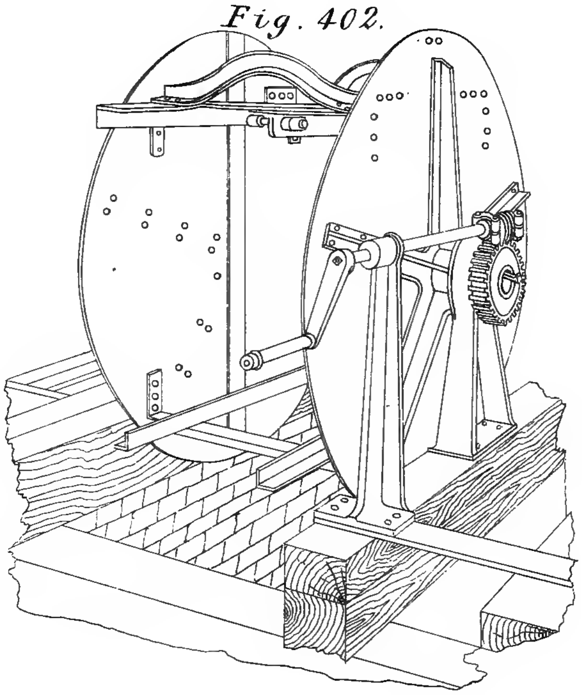


Fig. 403.

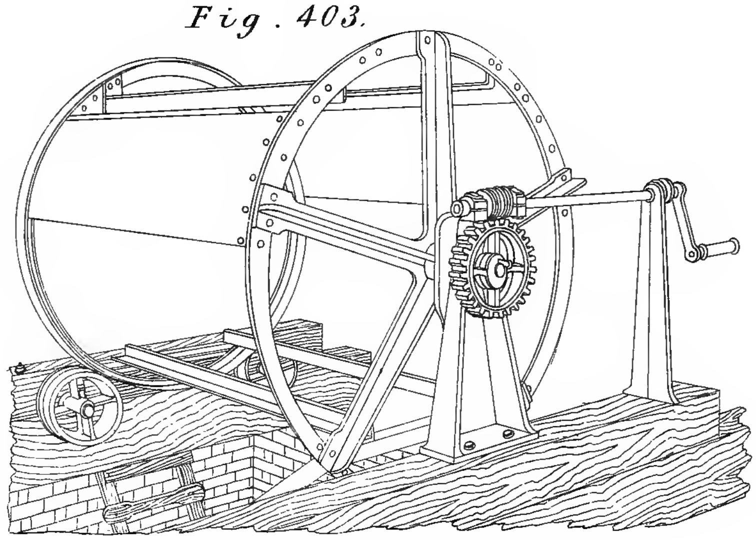


Fig. 406.

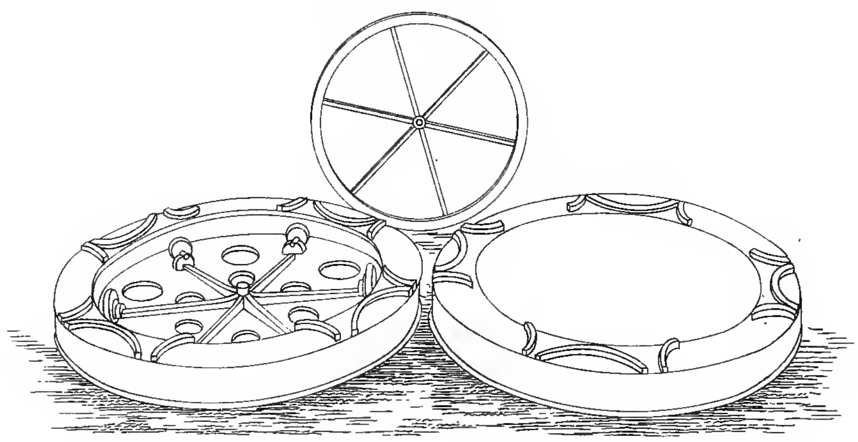


Fig. 405.

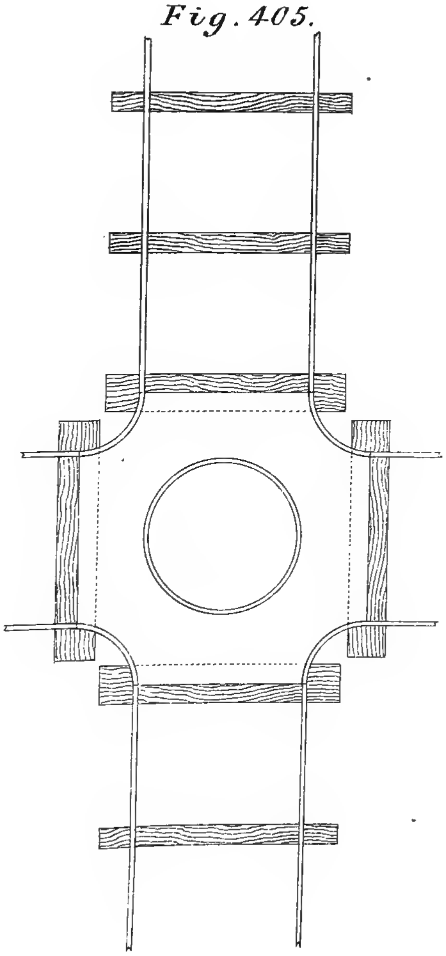
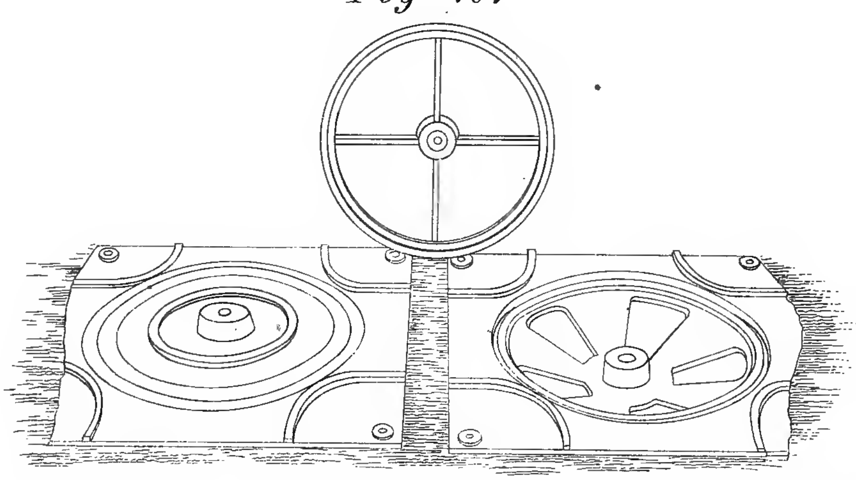


Fig 407



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SHEAVES, PULLEYS,

Fig. 408.

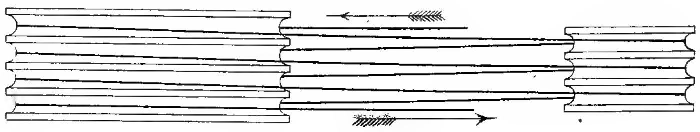


Fig. 409.

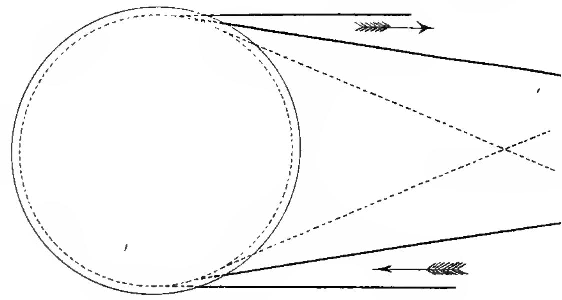


Fig. 410.

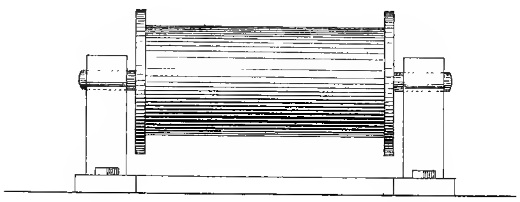


Fig. 411.

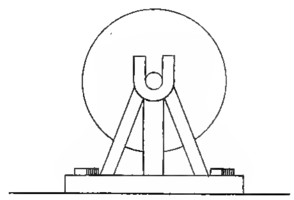


Fig. 412

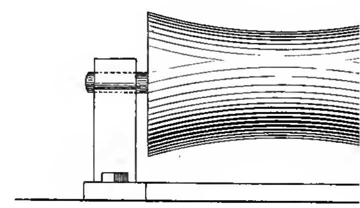


Fig. 416.

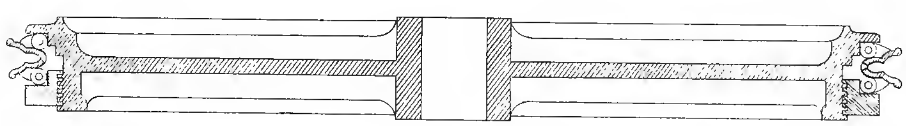


Fig. 413.

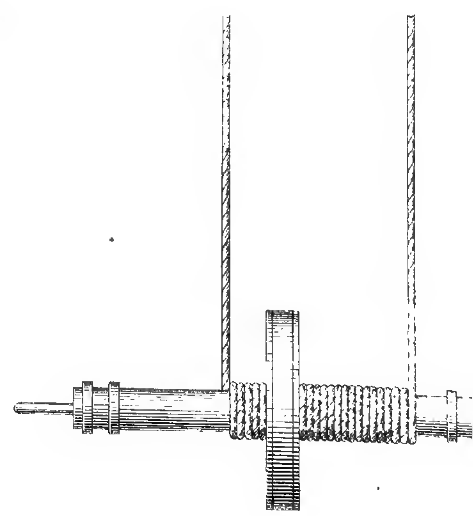
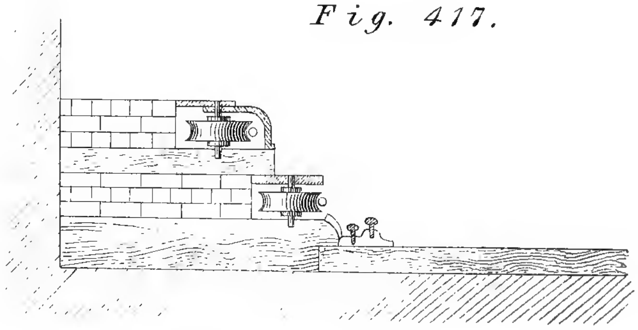


Fig. 417.



E.&F.N.S

AND FRICTION ROLLERS.

Fig. 414.

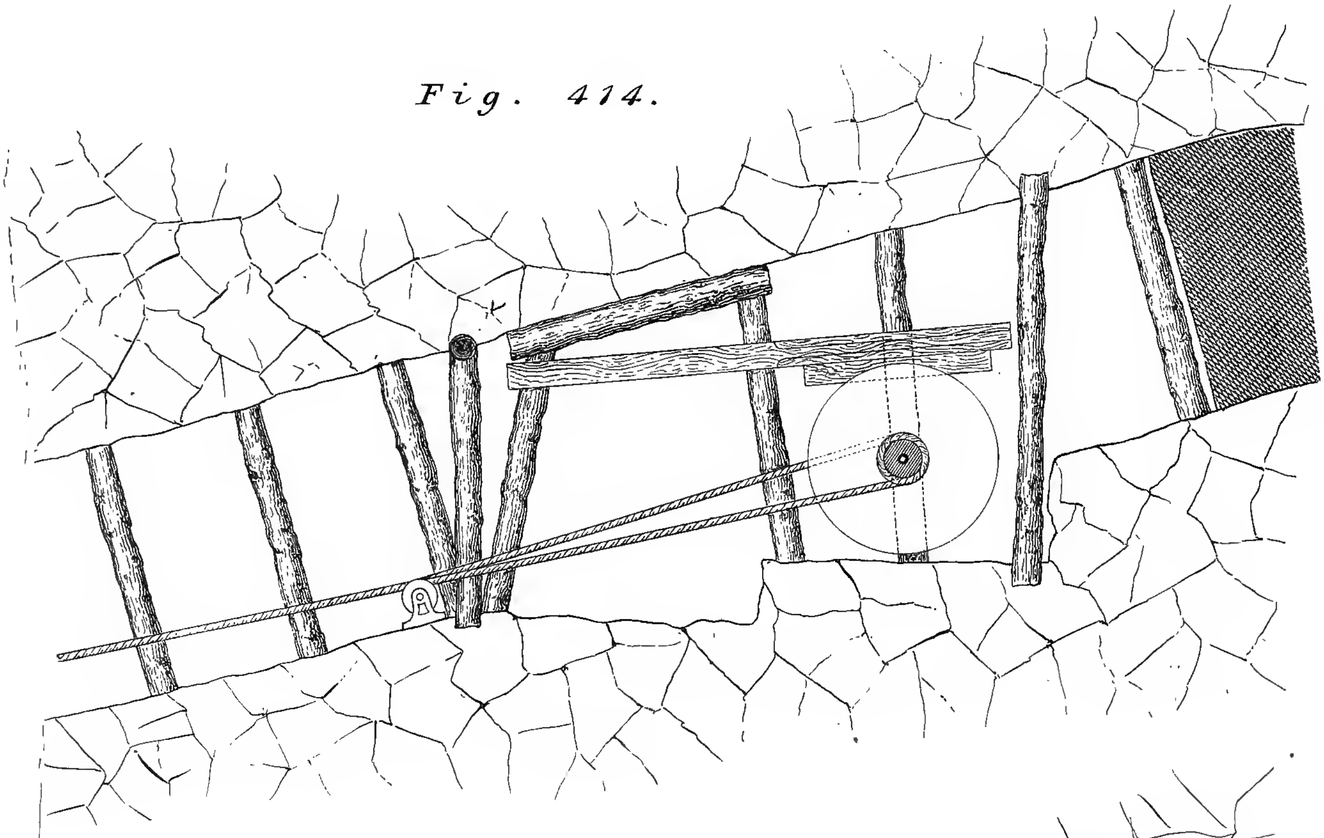
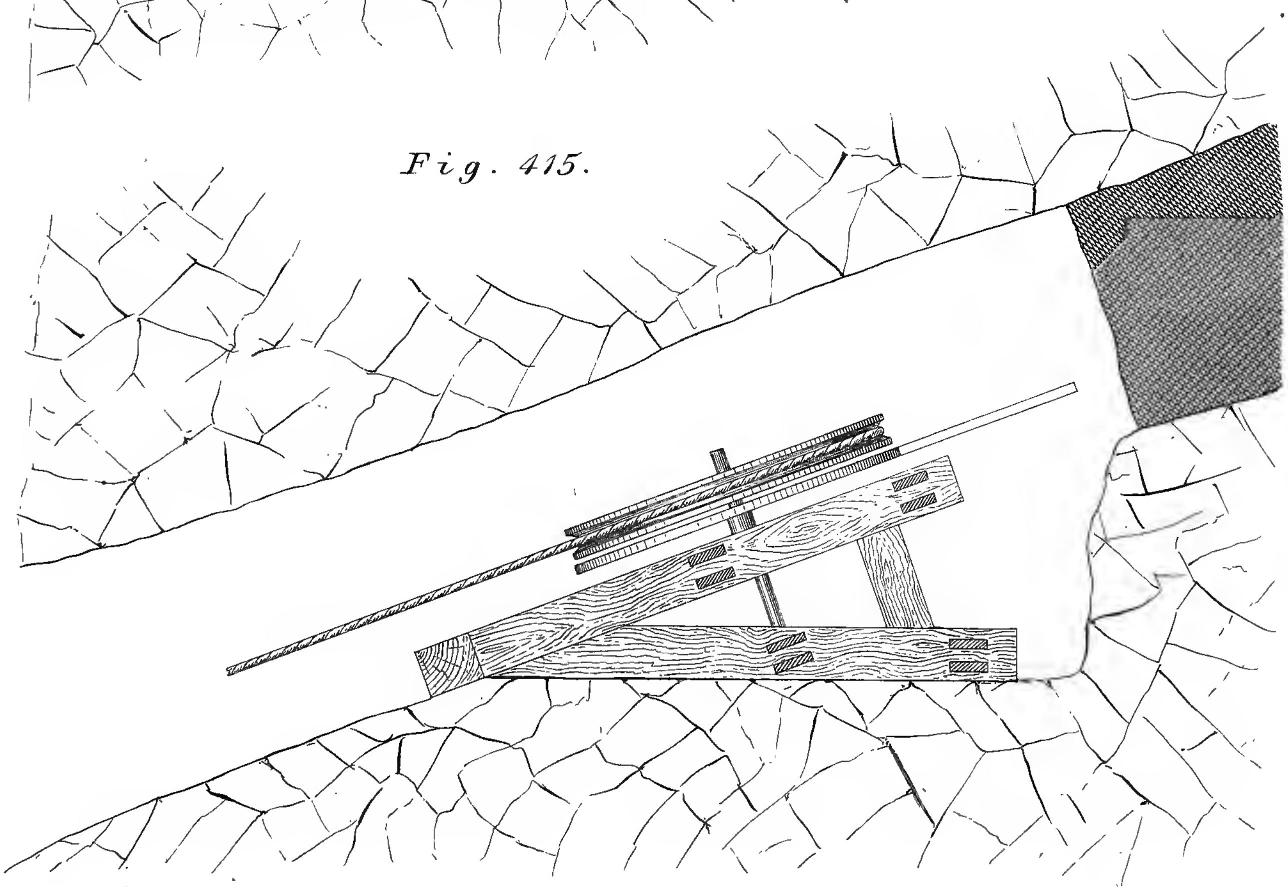


Fig. 415.



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TIGHTENING PULLEYS AND CONNECTIONS.

Fig. 418.

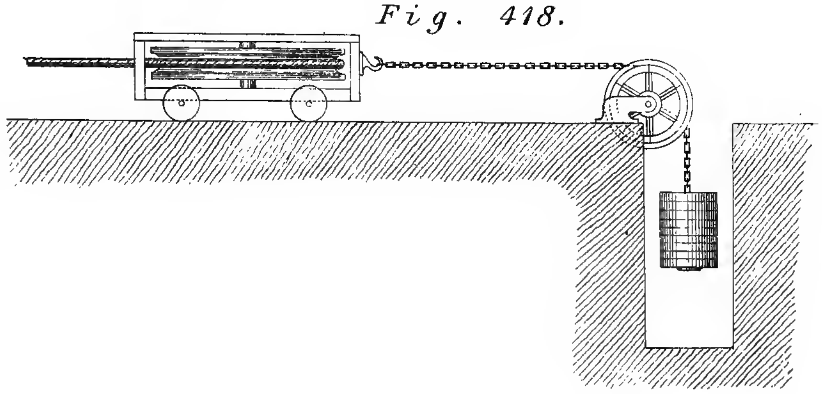


Fig. 423.

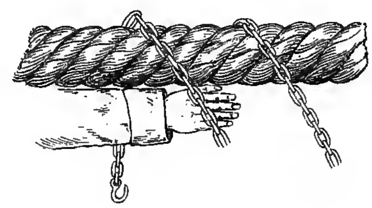


Fig. 419.

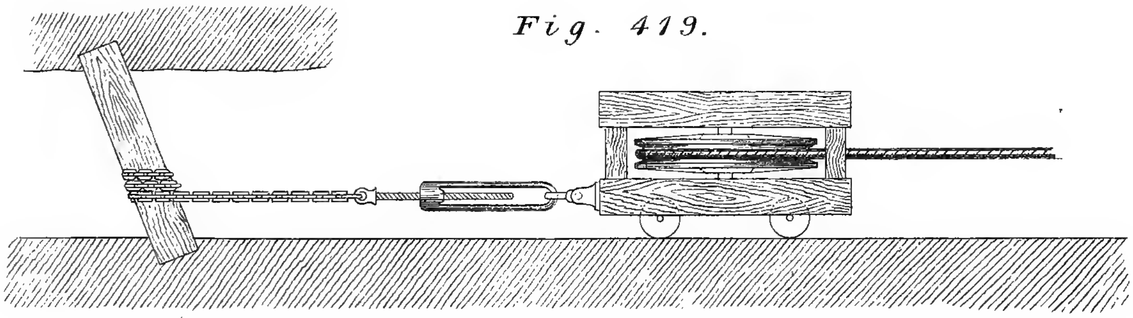


Fig. 420.

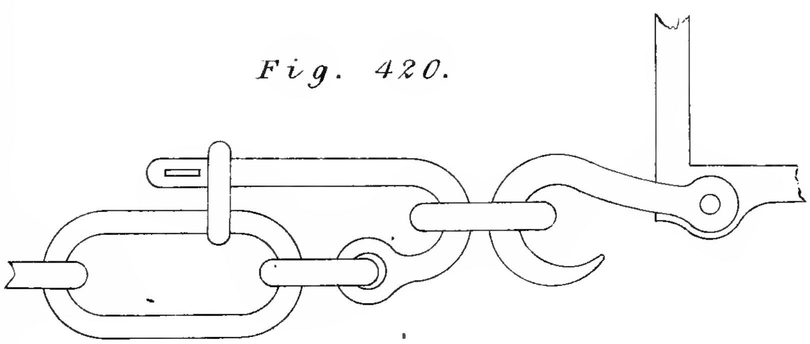


Fig. 421.

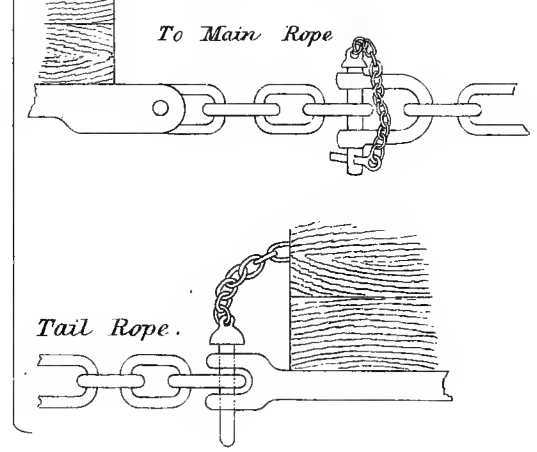


Fig. 422.

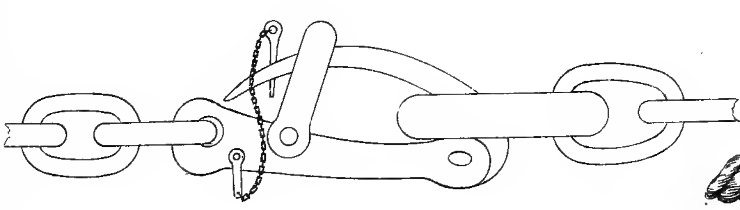
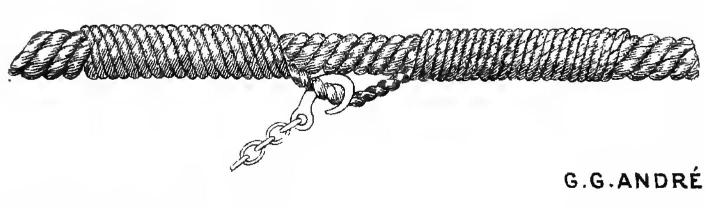


Fig. 424.



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